New 2016 Integral Benchmark Data from ICSBEP and IRPhEP

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Acknowledgments

The ICSBEP and IRPhEP are a collaborative effort

- Scientists, engineers, administrative support, program sponsors
- *****25 different countries have participated
 - $_{\odot}$ 22 in ICSBEP
 - 21 in IRPhEP

Without these dedicated individuals, these benchmark projects would not exist.





INTERNATIONAL BENCHMARK PROGRAMS

BETTER POLICIES FOR BETTER LIVES

Idaho National Laboratory

NEA

Benchmark Benchmark Evaluation Process Future Use Experiment Data Advanced Modeling and Simulation Externally Available Technical Journals & Reports Analytical Methods Evaluation Development, Validation, Process Internal Reports Letters & Memos and Verification Identify **Reactor Design** Short-Term Preservation and Licensing • Verify Logbooks Peer Review Training • Evaluate (National and -----Drawings International Criticality and Reactor • Compile Safety Analysis Experts) • Calculate Experimenter's Annotated Fuel Cycle and Related Document Copy of Published Reports Comprehensive Activities Source of Externally Range of Applicability and Peer Reviewed Integral Experimenters (Retired or Experiment Design Working on Other Projects) **Benchmark Data** Nuclear Data Refinement Facilities Awaiting D&D

International Handbook of Evaluated Criticality Safety Benchmark Experiments

September 2016 Edition

- > 22 Contributing Countries
- ~69,000 Pages
- 570 Evaluations
 - 4,913 Critical, Near-Critical, or Subcritical Configurations
 - 45 Criticality-Alarm-Placement/Shielding Configurations
 - 215 Configurations with Fundamental Physics Measurements
 - 829 Unacceptable Experiment Configurations



http://icsbep.inl.gov/



https://www.oecd-nea.org/science/wpncs/icsbep/

Breakdown of Current ICSBEP Benchmark Specifications

- 748 plutonium experiments
 - ✤ 36 compound
 - 123 metal
 - ✤ 589 solution
- 1435 highly enriched uranium experiments
 - 291 compound
 - ✤ 601 metal
 - ✤ 536 solution
 - ✤ 2 mixed compound/solution
 - ✤ 5 mixed metal/solution
- 268 intermediate- and mixedenrichment uranium experiments
 - 156 compound
 - ✤ 47 metal
 - ✤ 65 solution
- 1662 low enriched uranium experiments
 - ✤ 1398 compound
 - ✤ 87 metal
 - 117 solution
 - ✤ 60 mixed compound/solution

> 244 ²³³U experiments

- 6 compound
- 11 metal
- 227 solution
- 536 mixed plutonium-uranium experiments
 - 301 compound
 - 52 metal
 - 86 solution
 - ✤ 76 mixed compound/solution
 - 21 mixed metal/compound
 - 20 special isotope experiments
 - metal (²³⁷Np, ²³⁸Pu, ²⁴²Pu, & ²⁴⁴Cm)
- 9 criticality-alarm/shielding experiments
 - 45 unique configurations with numerous dose points
- > 8 fundamental physics experiments
 - 215 unique measurements such as fission rates, transmission measurements, and subcritical neutron multiplication measurements

F



Recent Revisions to the Handbook

6 Revisions

- PU-MET-FAST-001
 - Jezebel
 - Updated masses for components
- ✤ PU-MET-INTER-002
 - o **ZPR-6/10**
 - Improved uncertainty analysis

HEU-MET-FAST-028

- Flattop
- Updated sample calculations

✤ LEU-COMP-THERM-061

- VVER Lattice
- Fixed Hf absorber rod diameter error in figure

LEU-COMP-THERM-071

- o UO2 Rod Arrays
- Improved uncertainty analysis
- FUND-NCERC-PU-HE3-MULT-001
 - Ni-Reflected Pu Sphere
 - Revised uncertainty analysis for leakage multiplication





Revision: PU-MET-FAST-001

- LANL Jezebel
 - ✤Pu Sphere
 - Jeff Favorite

Discovered mass accountability statements, drawings, and logbooks



Table 51. Sample Calculation Results (Using MCNP6.1®, ENDF/B-VII.1) for the Detailed Models.

Case	Configuration	Calculated k _{eff}	Benchmark k _{eff}	Calc. – Bench. (pcm)	Calc. – Bench. (std. devs.)
1	А	1.00067 ± 0.00002	0.99999 ± 0.00110	68	0.61
2	В	1.00123 ± 0.00002	1.00016 ± 0.00110	107	0.96
3	С	1.00092 ± 0.00002	1.00020 ± 0.00110	72	0.64
4	D	1.00191 ± 0.00002	1.00128 ± 0.00110	63	0.56



Revision: PU-MET-INTER-002

≻ ANL – ZPR-6/10

- Pu/C/SST Assembly Reflected by SS/Fe
 Rich Lell
- Updated uncertainty analysis based on results from more recent ZPR/ZPPR benchmark evaluations





Table 4.1. Sample Calculation Results for Case 1, ZPR-6/10 Loading 24.

Code	Cross	Calcu	lation	С/Е -	1
	Sections	k _{eff}	σ	C/E-1, %	σ, %
KENO V.a	238-Group ENDF/B-V	1.0269	0.0009	3.96	0.26
KENO V.a	27-Group ENDF/B-IV	1.0262	0.0009	3.89	0.26
MCNP-4B	Cont. Energy ENDF/B-V	1.0038	0.0010	1.62	0.26
MCNP-4C	Cont. Energy ENDF/B-V	0.9945	0.0005	0.68	0.24
MCNP-4C	Cont- Energy ENDF/B-VI	1.0245	0.0005	3.72	0.25
VIM	Cont. Energy ENDF/B-V	0.9862	0.0005	-0.16	0.24
VIM	Cont. Energy ENDF/B-VI	1.0222	0.0006	3.48	0.25
MONK-8B ^(a)	8220-Group UKNDL	1.0444	0.0009	5.73	0.26
MONK-8B ^(a)	13193-Group JEF-2.2	1.0115	0.0009	2.40	0.26
MONK-8B ^(a)	13193-Group ENDF/B-VI	1.0324	0.0009	4.52	0.26
MCNP6	Cont. Energy ENDF/B-VII.1	1.0148	0.0001	2.73	0.24

Revision: HEU-MET-FAST-028

LANL – Flattop

- HEU Sphere Reflected by Nat-U
 Roger Brewer
- > Updated sample calculations from
 - Jeff Favorite
 - Discrepancy noted in previously calculated results



Table 3. Sample Calculation Results (United States).^(a)

Code Name	Cross-Section Set	Calculated k _{eff}
KENO	Hansen-Roach (16 groups, no self-shielding)	0.9955 ± 0.0013
KENO	ENDF/B-IV (27 groups)	1.0050 ± 0.0012
MCNP6.1.1®	ENDF/B-V (Continuous-energy)	1.00422 ± 0.00001
MCNP6.1.1®	ENDF/B-VI.2 (Continuous-energy)	1.00248 ± 0.00001
MCNP6.1.1®	ENDF/B-VII.0 (Continuous-energy)	1.00288 ± 0.00001
MCNP6.1.1®	ENDF/B-VII.1 (Continuous-energy)	1.00284 ± 0.00001
ONEDANT	ENDF/B-IV (27 groups)	1.0076
PARTISN	ENDF/B-V (30 groups, no shelf-shielding)	0.99756
PARTISN	ENDF/B-VII.0 (30 groups, no self-shielding)	1.00262
PARTISN	ENDF/B-VII.0 (618 groups, no self-shielding)	1.00239

(a) Results reported with four decimal places appeared in Revision 1 of this evaluation (Sept. 1999). Results reported with five decimal places were calculated by Jeffrey A. Favorite, Los Alamos National Laboratory, in April 2016 for Revision 2 of this evaluation.



Revision: LEU-COMP-THERM-061

> Kurchatov

- VVER Physics Experiments
- ♦ P-Facility
- Corrected error in benchmark diagram for absorber rod diameter
 - Figure 8





Revision: LEU-COMP-THERM-071

- LEU O2 Fuel Rod Array (CEA, Valduc)
 - Nicolas Leclaire (IRSN)
- Updated uncertainty analysis, especially rod position uncertainty
- New photographs
- Updated sample calculations





Revision: FUND-NCERC-PU-HE3-MULT-001

- NCERC Ni-Reflected Pu Sphere
 - Benoit Richard
 - Jesson Hutchenson
- Revised uncertainty analysis for leakage multiplication, M_L





Recent Additions to the Handbook

≻6 New

♦ HEU-MET-FAST-083

 Complex HEU Annuli

♦ HEU-MET-FAST-096

 Critical Experiments for SORA Reactor

LEU-COMP-THERM-097

 7uPCX AI/Ti Rod Experiments

ALARM-TRAN-PB-SHIELD-001

 Fissile Solution Critical Excursion

ALARM-TRAN-CH2-SHIELD-001

- Fissile Solution Critical Excursion
- *FUND-NCERC-PU-HE3-MULT-002

o W-Reflected Pu Sphere





New: HEU-MET-FAST-083

Complex HEU Annuli (ORCEF)

♦ISU – Quinton Bealieu

J. T. Mihalczo experiments to test complex geometry capability of early Monte Carlo codes with off-centered geometries

Casa	С	Calculated			Benchmark Experiment			
Case	$\mathbf{k}_{\mathrm{eff}}$	±	σ	$\mathbf{k}_{\mathrm{eff}}$	±	σ	$\frac{1}{E}$	
1 – Annulus with Cylinder	0.99693	±	0.00002	1.0001	±	0.0006	-0.31	
2 – Annulus with Parallelepiped	0.99842	±	0.00002	0.9993	±	0.0012	-0.09	
3 – Annulus with Split Parallelepiped	0.99616	±	0.00002	0.9984	±	0.0009	-0.22	

New: HEU-MET-FAST-096

SORA Critical **Experiments** (ORCEF) Liu Xiaobo (China) > J. T. Mihalczo experiments to mockup iron matrix and reflected pulse reactor



DIMENSIONS IN cm





HEU-MET-FAST-096 Results



	Casa	Case Calculated			Benchmark Experiment			$C - E_{ov}$		
	Case	Δk_{eff}	±	σ_{MC}	Δk_{eff}	±	σ	\overline{E} %		0
	1	0.99777	±	0.00004	1.0022	±	0.0024	-0.45	±	0.24
	2	0.99845	±	0.00004	1.0021	±	0.0024	-0.37	±	0.24
Be	3	1.00050	±	0.00004	1.0014	±	0.0025	-0.09	±	0.24
"Pulse" Reflector	4	0.99883	±	0.00004	1.0020	±	0.0025	-0.32	±	0.24
	5	1.00066	±	0.00004	1.0023	±	0.0026	-0.17	±	0.24
	6	1.00009	±	0.00004	1.0017	±	0.0026	-0.16	±	0.24
	7	0.99637	±	0.00004	1.0007	±	0.0026	-0.43	±	0.25
	8	0.99722	±	0.00004	1.0019	±	0.0025	-0.46	±	0.24
	9	0.99960	±	0.00004	1.0017	±	0.0025	-0.21	±	0.24
	10	0.99582	±	0.00004	1.0014	±	0.0025	-0.55	±	0.25
	11	0.99451	±	0.00004	1.0013	±	0.0023	-0.68	±	0.25
Fe	12	0.99390	±	0.00004	1.0013	±	0.0024	-0.74	±	0.25
"Pulse"	13	1.00106	±	0.00004	1.0032	±	0.0023	-0.21	±	0.24
Reflector	14	0.99299	±	0.00004	1.0008	±	0.0024	-0.78	±	0.25
	15	0.99815	±	0.00004	1.0017	±	0.0024	-0.35	±	0.24



New: LEU-COMP-THERM-097

> Ti/AI Rods in 6.9% Enriched UO2 Lattices

♦ Gary Harms – SNL

> 21 experiments designed to test titanium nuclear data





LEU-COMP-THERM-097 Results



ENDF/B-VII.1 Library.

Figure 73. Reactivity Offset for MCNP6.1.1 Calculations using Continuous-Energy Cross Sections from the Figure 72. Reactivity Offset for KENO V.a Calculations using Continuous-Energy Cross Sections from the ENDF/B-VII.1 SCALE6.2 Library.



New: ALARM-TRAN-CH2-SHIELD-001

- Valduc SILENE with CH2 Reflector
 - Thomas Miller (ORNL)
- Neutron activation and thermoluminescent dosimeter responses





Table 4-8. Sample Neutron Activation Calculation Results with MCNP6 ENDF/B-VII.1 (US).

ALARM-TRAN-CH2 -SHIELD-001 Results

Position Case 1 collimator A	$\frac{^{59}C \otimes (n,\gamma)^{60}C \otimes ^{197}Au(n,\gamma)^{198}Au}{^{115}In(n,\gamma)^{116}In}$ $^{115}In(n,n'\gamma)^{115m}In$ $^{56}Fe(n,p)^{56}Mn + $	Activity (Bq/g) -4:644E+00- 5.801E+03 6.407E+05 8.269E+02	Monte Carlo relative uncertainty 0.0024 0.0030 0.0032 0.0020	C/E -1.0206- 0.8911 0.9591 0.8327	C/E relative uncertainty -0:0683 -0.0716 -0.0691 -0.0630 -0.0638	
	$^{55}Mn(n,\gamma)^{56}Mn$	1.7221+02	0.0025	0.9105	0.0038	
	-Mg(n,p)-Na	1.608E+01	0.0036	0.9928	0.0/4/	
	⁵⁰ N1(n,p) ⁵⁰ Co	1.939E+00	0.0018	0.9005	0.0654	
	$^{33}Co(n,\gamma)^{00}Co$	7.427E-01	0.0024	1.1253	0.0855	
	197 Au(n, γ) 198 Au	1.091E+03	0.0033	0.9314	0.0798	
Case 2	115 In $(n,\gamma)^{110}$ In	9.983E+04	0.0033	0.9092	0.0825	
collimator B	115 In(n,n' γ) 115m In	3.595E+02	0.0019	0.8746	0.0722	
commator D	56 Fe(n,p) 56 Mn + 55 Mn(n, γ) 56 Mn	3.775E+01	0.0022	0.9075	0.0749	
	$^{24}Mg(n,p)^{24}Na$	8.019E+00	0.0034	1.0428	0.0774	
	${}^{59}Co(n,\gamma){}^{60}Co$	5.448E+00	0.0033	1.0896	0.0692	
	$^{197}Au(n,\gamma)^{198}Au$	5.860E+03	0.0043	1.0559	0.0648	
	$^{115}In(n,\gamma)^{116}In$	6.648E+05	0.0035	1.1326	0.0725	
Case 3	115 In(n,n' γ) ^{115m} In	7.067E+02	0.0021	0.8403	0.0683	
free field	56 Fe(n,p) 56 Mn + 55 Mn(n, γ) 56 Mn	2.110E+02	0.0037	0.9859	0.0671	
	$^{24}Mg(n,p)^{24}Na$	1.575E+01	0.0044	1.0712	0.0801	
	⁵⁸ Ni(n,p) ⁵⁸ Co	1.800E+00	0.0025	1.0033	0.0634	
	⁵⁹ Co(n,γ) ⁶⁰ Co	2.577E+00	0.0016	1.1894	0.0729	
	$^{197}Au(n,\gamma)^{198}Au$	2.548E+03	0.0020	1.0798	0.0739	
Case 4	115 In(n, γ) ¹¹⁶ In	3.034E+05	0.0019	1.1448	0.0743	
scattering box 1	115 In(n,n' γ) 115m In	5.681E+01	0.0034	0.9661	0.0994	
	56 Fe(n,p) 56 Mn + 55 Mn(n, γ) 56 Mn	9.111E+01	0.0021	1.1636	0.0685	
Case 5	⁵⁹ Co(n,γ) ⁶⁰ Co	3.040E+00	0.0013	1.2078	0.0709	
scattering box 2	$^{197}Au(n,\gamma)^{198}Au$	2.951E+03	0.0018	1.1763	0.0688	
Case 6	⁵⁹ Co(n,γ) ⁶⁰ Co	4.327E+00	0.0014	1.1065	0.0717	
scattering box 3	$^{197}Au(n,\gamma)^{198}Au$	4.336E+03	0.0018	1.1089	0.0681	
Case 7	⁵⁹ Co(n, γ) ⁶⁰ Co	3.953E+00	0.0013	1.1388	0.0696	
scattering box 4	$^{197}Au(n,\gamma)^{198}Au$	3.888E+03	0.0017	1.0595	0.0730	

Table 4-9. Sample TLD Dose Calculation Results with MCNP6 ENDF/B-VII.1 (US).

Position	TLD Type	Dose (Gy)	Monte Carlo relative uncertainty	C/E	C/E relative uncertainty
Case 1 collimator A	Al_2O_3	3.314E+00	0.0071	0.6265	0.0787
Case 2 collimator B	Al_2O_3	1.902E+00	0.0044	0.6040	0.0832
Case 3 free field	Al_2O_3	3.130E+00	0.0041	0.6535	0.0917
Case 6 scattering box 3	Al_2O_3	6.628E-01	0.0034	0.6563	0.0846
Case 7 scattering box 4	Al ₂ O ₃	7.478E-01	0.0058	0.6560	0.0784

OFAI	\sim

New: ALARM-TRAN -PB-SHIELD-001

- Valduc SILENE with Pb Reflector
 - Thomas Miller (ORNL)
- Neutron activation and thermoluminescent dosimeter responses





2 mm

Table 4-10. Sample neutron activation calculation results with SCALE 6.2 ENDF/B-VII.1 (US)

ALARM-TRAN-PB -SHIELD-001 Results

Table 4-11. Sample TLD dose calculation results with SCALE 6.2 ENDF/B-VII.1 (US

Position	TLD Type	Dose (Gy)	Monte Carlo relative uncertainty	C/E	C/E relative uncertainty
Case 1 collimator A	Al ₂ O ₃	6.909E-01	0.0837	0.84	0.1164
Case 2 collimator B	Al ₂ O ₃	4.264E-01	0.0270	0.78	0.1217
Case 3 free field	Al ₂ O ₃	3.101E-01	0.1289	0.55	0.1509
Case 6 scattering box 3	Al ₂ O ₃	3.178E-01	0.0885	0.76	0.1183

$ \begin{array}{c} \frac{5^{9}{\rm Co}(n,\gamma)^{60}{\rm Co} & 7.001{\rm E}{+01} & 0.0458 & 1.15 & 0.0841 \\ \frac{19^{7}}{\rm Au}(n,2)^{98}{\rm Au} & 8.20{\rm E}{\rm E}{\rm A04} & 0.0333 & 1.19 & 0.0758 \\ \frac{115\ln(n,r)^{115m}{\rm In} & 5.761{\rm E}{+06} & 0.0481 & 1.21 & 0.0886 \\ \hline {\rm Case 1} & \frac{115\ln(n,r)^{915m}{\rm Mn} & 5.761{\rm E}{+03} & 0.0188 & 0.94 & 0.0661 \\ \frac{5^{67}{\rm Ce}(n,p)^{56}{\rm Mn} & 2.297{\rm E}{+03} & 0.0317 & 1.14 & 0.0759 \\ \frac{2^{4}{\rm Mg}(n,p)^{24}{\rm Na} & 3.367{\rm E}{+01} & 0.0229 & 1.36 & 0.0686 \\ \frac{5^{88}{\rm Ni}(n,p)^{98}{\rm Co} & 7.818{\rm E}{+00} & 0.0166 & 1.14 & 0.0657 \\ \frac{5^{97}{\rm Co}(n,r)^{60}{\rm Co} & 3.8381{\rm E}{+01} & 0.0033 & 1.20 & 0.0784 \\ \frac{19^{7}{\rm Au}(n,r)^{115m}{\rm In} & 4.690{\rm E}{+06} & 0.0035 & 1.22 & 0.0842 \\ \hline {\rm Case 2} & \frac{115\ln(n,r)^{115m}{\rm In} & 4.690{\rm E}{+06} & 0.0033 & 1.21 & 0.0784 \\ \frac{19^{7}{\rm Au}(n,r)^{115m}{\rm In} & 9.600{\rm E}{+02} & 0.0071 & 1.02 & 0.1076 \\ \hline {\rm collimator B} & \frac{5^{67}{\rm Co}(n,r)^{60}{\rm Co} & 3.641{\rm E}{+01} & 0.0404 & 1.22 & 0.0811 \\ \frac{19^{7}{\rm Au}(n,r)^{115m}{\rm In} & 1.257{\rm E}{+03} & 0.0033 & 1.21 & 0.0741 \\ \hline {\rm s}^{58}{\rm Ni}(n,p)^{56}{\rm Co} & 1.475{\rm E}{+00} & 0.0151 & 1.26 & 0.1196 \\ \frac{5^{8}{\rm Ni}(n,p)^{56}{\rm Co} & 1.475{\rm E}{+00} & 0.0077 & 1.16 & 0.1120 \\ \hline {\rm s}^{59}{\rm Co}(n,r)^{16m}{\rm In} & 8.74{\rm E}{+06} & 0.0414 & 1.13 & 0.0822 \\ 115\ln(n,r^{7})^{115m}{\rm In} & 5.176{\rm E}{+03} & 0.0297 & 0.99 & 0.0698 \\ \hline {\rm free field} & \frac{5^{67}{\rm Ce}(n,p)^{56}{\rm Mn} + 2.55{\rm Ce}{+01} & 0.0376 & 1.24 & 0.0823 \\ \frac{19^{7}{\rm Au}(n,r)^{198}{\rm Au} & 3.091{\rm E}{+01} & 0.0277 & 1.17 & 0.0760 \\ \frac{5^{9}{\rm Ni}(n,p)^{58}{\rm Co} & 7.235{\rm E}{+00} & 0.0143 & 1.24 & 0.076 \\ \frac{19^{7}{\rm Au}(n,r)^{115m}{\rm In} & 3.429{\rm E}{+02} & 0.0368 & 1.06 & 0.1113 \\ \frac{5^{6}{\rm Ce}(n,r)^{56}{\rm Mn} + \frac{3.653{\rm E}{+06} & 0.0143 & 1.20 & 0.1358 \\ \frac{5^{8}{\rm Ni}(n,p)^{58}{\rm Co} & 3.521{\rm E}{+01} & 0.0161 & 1.25 & 0.0749 \\ \frac{19^{7}{\rm Au}(n,r)^{115m}{\rm In} & 3.429{\rm E}{+02} & 0.0368 & 1.06 & 0.1113 \\ \frac{5^{6}{\rm Ce}(n,r)^{56}{\rm Mn} + \frac{3.525{\rm E}{+01} & 0.0161 & 1.25 & 0.0774 \\ \frac{19^{7}{\rm Au}(n,r)^{115m}{\rm Na} & 3.252{\rm E}{+01} & 0.0163 & 1.27 $		Position	Position Reaction		Monte Carlo relative uncertainty	C/E	C/E relative uncertainty	
$\begin{array}{c} & \frac{197}{4} \mathrm{Au}(n,z)^{198} \mathrm{Au} & 8.206 \mathrm{E}_{4} \mathrm{O4} & 0.0333 & 1.19 & 0.075 \mathrm{s} \\ & \frac{115}{1} \mathrm{n}(n,\gamma)^{116} \mathrm{n} & 9.615 \mathrm{E}_{4} \mathrm{O6} & 0.0481 & 1.21 & 0.0886 \\ & \frac{115}{1} \mathrm{n}(n,\gamma)^{116} \mathrm{n} & 5.761 \mathrm{E}_{4} \mathrm{O3} & 0.0188 & 0.94 & 0.0661 \\ & \frac{56}{9} \mathrm{N}(n,\gamma)^{50} \mathrm{Mn} & 2.297 \mathrm{E}_{4} \mathrm{O3} & 0.0317 & 1.14 & 0.0759 \\ & \frac{2^4 \mathrm{Mg}(n,p)^{24} \mathrm{Na} & 3.367 \mathrm{E}_{4} \mathrm{O1} & 0.0229 & 1.36 & 0.0686 \\ & \frac{58}{10} \mathrm{N}(n,\gamma)^{50} \mathrm{Co} & 7.818 \mathrm{E}_{4} \mathrm{O0} & 0.0166 & 1.14 & 0.0657 \\ & \frac{5^6 \mathrm{Co}(n,\gamma)^{60} \mathrm{Co} & 3.833 \mathrm{E}_{4} \mathrm{O1} & 0.0016 & 1.14 & 0.0657 \\ & \frac{5^6 \mathrm{Co}(n,\gamma)^{60} \mathrm{Co} & 3.8381 \mathrm{E}_{4} \mathrm{O1} & 0.0016 & 1.125 & 0.0831 \\ & \frac{10^5 \mathrm{In}(n,n^{+}\gamma)^{115} \mathrm{m} & 4.690 \mathrm{E}_{4} \mathrm{O2} & 0.0071 & 1.02 & 0.1076 \\ & \frac{567 \mathrm{Co}(n,\gamma)^{60} \mathrm{Mn} & 1.257 \mathrm{E}_{4} \mathrm{O3} & 0.0033 & 1.21 & 0.0741 \\ & \frac{567 \mathrm{Co}(n,\gamma)^{60} \mathrm{Mn} & 1.257 \mathrm{E}_{4} \mathrm{O3} & 0.0033 & 1.21 & 0.0741 \\ & \frac{2^4 \mathrm{Mg}(n,p)^{24} \mathrm{Na} & 6.949 \mathrm{E}_{4} \mathrm{O0} & 0.0151 & 1.26 & 0.1196 \\ & \frac{58} \mathrm{Ni}(n,p)^{58} \mathrm{Co} & 1.475 \mathrm{E}_{4} \mathrm{O0} & 0.0077 & 1.16 & 0.1120 \\ & \frac{5^6 \mathrm{Co}(n,\gamma)^{60} \mathrm{Mn} & 7.825 \mathrm{E}_{4} \mathrm{O} & 0.0077 & 1.16 & 0.1120 \\ & \frac{5^6 \mathrm{Co}(n,\gamma)^{60} \mathrm{Mn} & 7.825 \mathrm{E}_{4} \mathrm{O} & 0.0297 & 0.99 & 0.0698 \\ \mathrm{free field} & \frac{5^6 \mathrm{Fe}(n,p)^{50} \mathrm{Mn} + 2.560 \mathrm{E}_{4} \mathrm{O} & 0.0376 & 1.22 & 0.0832 \\ & \frac{115}{1} \mathrm{n}(n,\gamma)^{115} \mathrm{m} \mathrm{n} & 5.176 \mathrm{E}_{4} \mathrm{O} & 0.0376 & 1.24 & 0.0822 \\ & \frac{19^7 \mathrm{Au}(n,\gamma)^{198} \mathrm{Au} & 3.091 \mathrm{E}_{4} \mathrm{O} & 0.0376 & 1.24 & 0.0828 \\ & \frac{19^7 \mathrm{Au}(n,\gamma)^{116} \mathrm{m} & 3.653 \mathrm{E}_{4} \mathrm{O} & 0.0376 & 1.24 & 0.0828 \\ & \frac{19^7 \mathrm{Au}(n,\gamma)^{116} \mathrm{m} & 3.632 \mathrm{E}_{4} \mathrm{O} & 0.0314 & 1.24 & 0.0776 \\ & \frac{19^5 \mathrm{Au}(n,\gamma)^{116} \mathrm{m} & 3.632 \mathrm{E}_{4} \mathrm{O} & 0.0314 & 1.24 & 0.0776 \\ & \frac{19^7 \mathrm{Au}(n,\gamma)^{116} \mathrm{m} & 3.298 \mathrm{E}_{4} \mathrm{O} & 0.0163 & 1.27 & 0.0174 \\ & \frac{5^6 \mathrm{Co}(n,\gamma)^{60} \mathrm{Co} & 3.521 \mathrm{E}_{4} \mathrm{O} & 0.0161 & 1.25 & 0.0749 \\ & \frac{5^6 \mathrm{Co}(n,\gamma)^{60} \mathrm{Co} & 3.521 \mathrm{E}_{4} \mathrm{O} & 0.0163 & 1.27 & 0.0177 \\ & \frac{5^6 \mathrm{Co}(n,\gamma)^{60} \mathrm{Co} & 3.521 \mathrm{E}_{4} \mathrm{O} & 0.0163 & 1.27 & 0.07$	ĺ		⁵⁹ Co(n, γ) ⁶⁰ Co	7.001E+01	0.0458	1.15	0.0841	1
$ \begin{array}{c} \begin{array}{c} \begin{array}{c} \begin{array}{c} 11^{15} \mathrm{In}(\mathrm{n},\gamma)^{116} \mathrm{In} & 9.615 \mathrm{E}{+}06 & 0.0481 & 1.21 & 0.0886 \\ \mathrm{collimator}\mathrm{A} & \begin{array}{c} 11^{5} \mathrm{In}(\mathrm{n},\gamma)^{115m} \mathrm{In} & 5.761 \mathrm{E}{+}03 & 0.0188 & 0.94 & 0.0661 \\ \end{array}{} & \begin{array}{c} 55 \mathrm{Kn}(\mathrm{n},\gamma)^{56} \mathrm{Kn} & 2.297 \mathrm{E}{+}03 & 0.0317 & 1.14 & 0.0759 \\ \end{array}{} & \begin{array}{c} 2^{4} \mathrm{Mg}(\mathrm{n},\mathrm{p})^{24} \mathrm{Na} & 3.367 \mathrm{E}{+}01 & 0.0229 & 1.36 & 0.0686 \\ \end{array}{} & \begin{array}{c} 58 \mathrm{Ni}(\mathrm{n},\mathrm{p})^{56} \mathrm{Co} & 7.818 \mathrm{E}{+}00 & 0.0166 & 1.14 & 0.0657 \\ \end{array}{} & \begin{array}{c} 58 \mathrm{Ni}(\mathrm{n},\mathrm{p})^{56} \mathrm{Co} & 3.883 \mathrm{E}{+}01 & 0.0033 & 1.20 & 0.0784 \\ \end{array}{} & \begin{array}{c} 19^{7} \mathrm{Au}(\mathrm{n},\gamma)^{108} \mathrm{Au} & 3.883 \mathrm{E}{+}01 & 0.0033 & 1.22 & 0.0842 \\ \end{array}{} & \begin{array}{c} 10 \mathrm{In}(\mathrm{n},\gamma)^{116} \mathrm{In}(\mathrm{n},\gamma)^{116} \mathrm{In}(\mathrm{n},2) \mathrm{In}(\mathrm{s}) \mathrm{e}00 \mathrm{E}{+}02 & 0.0071 & 1.02 & 0.0176 \\ \end{array}{} & \begin{array}{c} \mathrm{case} 2 & 11^{5} \mathrm{In}(\mathrm{n},\gamma)^{56} \mathrm{Mn} & 1.257 \mathrm{E}{+}03 & 0.0033 & 1.21 & 0.0741 \\ \end{array}{} & \begin{array}{c} 58 \mathrm{Ni}(\mathrm{n},\mathrm{p})^{56} \mathrm{Co} & 1.475 \mathrm{E}{+}00 & 0.0151 & 1.26 & 0.1196 \\ \end{array}{} & \begin{array}{c} 58 \mathrm{Ni}(\mathrm{n},\mathrm{p})^{56} \mathrm{Co} & 1.475 \mathrm{E}{+}00 & 0.0077 & 1.16 & 0.1120 \\ \end{array}{} & \begin{array}{c} 59 \mathrm{Co}(\mathrm{n},\gamma)^{60} \mathrm{Co} & 7.641 \mathrm{E}{+}01 & 0.0409 & 1.22 & 0.0812 \\ \end{array}{} & \begin{array}{c} 10^{57} \mathrm{Au}(\mathrm{n},\gamma)^{198} \mathrm{Au} & 7.825 \mathrm{E}{+}04 & 0.0507 & 1.22 & 0.0812 \\ \end{array}{} & \begin{array}{c} 10^{57} \mathrm{Au}(\mathrm{n},\gamma)^{198} \mathrm{Au} & 7.825 \mathrm{E}{+}03 & 0.0297 & 0.99 & 0.0698 \\ \end{array}{} & \begin{array}{c} 56 \mathrm{Fe}(\mathrm{n},\mathrm{p})^{56} \mathrm{Mh} + 2.560 \mathrm{E}{+}03 & 0.0383 & 1.23 & 0.0749 \\ \end{array}{} & \begin{array}{c} 2^{24} \mathrm{Mg}(\mathrm{n},\mathrm{p})^{24} \mathrm{Na} & 2.987 \mathrm{E}{+}04 & 0.0376 & 1.24 & 0.0776 \\ \end{array}{} & \begin{array}{c} 10^{57} \mathrm{Au}(\mathrm{n},\gamma)^{198} \mathrm{Au} & 2.987 \mathrm{E}{+}04 & 0.0314 & 1.26 & 0.0822 \\ \end{array}{} & \begin{array}{c} 10^{57} \mathrm{Au}(\mathrm{n},\gamma)^{198} \mathrm{Au} & 2.987 \mathrm{E}{+}04 & 0.0316 & 1.24 & 0.0776 \\ \end{array}{} & \begin{array}{c} 10^{57} \mathrm{Au}(\mathrm{n},\gamma)^{168} \mathrm{Au} & 2.987 \mathrm{E}{+}04 & 0.0316 & 1.24 & 0.0776 \\ \end{array}{} & \begin{array}{c} 10^{57} \mathrm{Au}(\mathrm{n},\gamma)^{198} \mathrm{Au} & 2.987 \mathrm{E}{+}04 & 0.0314 & 1.26 & 0.0828 \\ \end{array}{} & \begin{array}{c} \mathrm{Au}(\mathrm{n},\gamma)^{198} \mathrm{Au} & 2.987 \mathrm{E}{+}04 & 0.0314 & 1.26 & 0.0323 \\ \end{array}{} & \begin{array}{c} \mathrm{Au}(\mathrm{n},\gamma)^{198} \mathrm{Au} & 2.987 \mathrm{E}{+}04 & 0.0314 & 1.26 & 0.0776 \\ \end{array}{} & \begin{array}{c} 10^{57} \mathrm{Au}(\mathrm{n},\gamma)^{198}$			$^{197}Au(n,\gamma)^{198}Au$	8.206E+04	0.0333	1.19	0.0758	
Case 1 $^{115}In(n,n'\gamma)^{115m}In$ 5.761E+03 0.0188 0.94 0.0661 $^{56}Fe(n,p)^{56}Mn$ 2.297E+03 0.0317 1.14 0.0759 $^{24}Mg(n,p)^{24}Na$ 3.367E+01 0.0229 1.36 0.0686 $^{58}Nin(n,p)^{56}Co$ 7.818E+00 0.0166 1.14 0.0657 $^{59}Co(n,p)^{69}Co$ 3.883E+04 0.0041 1.25 0.0831 $^{197}Au(n,p)^{116}In$ 4.690E+06 0.0035 1.22 0.0842 $^{115}In(n,p')^{115m}In$ 9.600E+02 0.0071 1.02 0.1076 $^{59}Co(n,p)^{56}Mn$ 1.257E+03 0.0033 1.21 0.0741 $^{55}Min(n,p)^{56}Mn$ 1.257E+03 0.0033 1.21 0.0741 $^{55}Min(n,p)^{56}Mn$ 1.257E+03 0.0033 1.21 0.0741 $^{55}Min(n,p)^{56}Mn$ 1.257E+03 0.0033 1.21 0.0741 $^{59}Co(n,p)^{60}Co$ 7.641E+01 0.0409 1.22 0.0812 $^{197}Au(n,p)^{198}Au$ 7.825E+04 0.0507 1.22 0.0832 $^{115}In(n,p)^{116}In$ 8.874E+06 0.0414 1.13 0.0822 Case 3 $^{115}In(n,p)^{116}In$ 8.874E+06 0.0414 1.13 0.0822 $^{115}In(n,p)^{116}In$ 8.874E+06 0.0277 0.99 0.0698 free field $^{56}Fe(n,p)^{56}Mn$ 4.2560E+03 0.0297 0.99 0.0698 $^{56}Fe(n,p)^{56}Mn$ 4.2560E+03 0.0297 0.99 0.0698 $^{56}Fe(n,p)^{56}Mn$ 4.2560E+01 0.0277 1.17 0.0760 $^{58}Ni(n,p)^{58}Co$ 7.235E+00 0.0209 1.14 0.0667 $^{58}Ni(n,p)^{58}Mn$ 4.2560E+01 0.0376 1.24 0.0828 $^{197}Au(n,p)^{198}Au$ 2.987E+04 0.0314 1.24 0.0776 $^{115}In(n,n'p)^{115m}In$ 3.429E+02 0.0368 1.06 0.1113 $^{56}Re(n,p)^{56}Mn$ 4.2560E+01 0.0376 1.24 0.0828 $^{197}Au(n,p)^{198}Au$ 2.987E+04 0.0143 1.20 0.0132 $^{24}Mg(n,p)^{24}Na$ 3.285E+04 0.0152 1.26 0.1323 $^{59}Co(n,p)^{60}Co$ 3.226E+01 0.0152 1.26 0.1323 $^{59}Co(n,p)^{60}Co$ 3.228E+04 0.0163 1.27 0.0717 $^{58}Ni(n,p)^{58}Co$ 4.076E+01 0.0277 1.20 0.0774 $^{59}Au(n,p)^{198}Au$ 3.285E+04 0.0163 1.27 0.0717 $^{59}Au(n,p)^{198}Au$ 3.285E+04 0.0163 1.27 0.0717 $^{59}Au(n,p)^{198}Au$ 3.285E+04 0.0357 1.20 0.0774 $^{59}Au(n,p)^{198}Au$ 3.285E+04 0.0357 1.20 0.0774 $^{59}Au(n,p)^{198}Au$ 4.889E+04 0.0357 1.20 0.0779 $^{58}Ni(n,p)^{58}Co$ 1.767E+00 0.0351 1			¹¹⁵ In(n,γ) ¹¹⁶ In	9.615E+06	0.0481	1.21	0.0886	
collimator A $\frac{5^{6}Fe(n,p)^{56}Mn + 2.297E+03}{5^{5}Mn(n,p)^{56}Mn} 2.297E+03 0.0317 1.14 0.0759$ $\frac{2^{4}Mg(n,p)^{24}Na 3.367E+01 0.0229 1.36 0.0686}{5^{8}Ni(n,p)^{58}Co} 7.818E+00 0.0166 1.14 0.0657$ $\frac{5^{9}Co(n,p)^{60}Co}{3.883E+01} 0.0033 1.20 0.0784$ $\frac{19^{7}Au(n,p)^{198}Au 3.883E+04 0.0041 1.25 0.0831$ $\frac{19^{7}Au(n,p)^{196}Mn + 6.90E+06 0.0035 1.22 0.0842$ collimator B $\frac{5^{6}Fe(n,p)^{56}Mn + 5^{5}Mn(n,p)^{56}Mn}{2^{4}Mg(n,p)^{24}Na 6.949E+00 0.0151 1.26 0.1196}$ $\frac{2^{4}Mg(n,p)^{24}Na 6.949E+00 0.0151 1.26 0.1196}{5^{8}Ni(n,p)^{56}Co} 1.475E+00 0.0077 1.16 0.1120$ $\frac{5^{9}Co(n,p)^{60}Co}{2.644E+01} 0.0409 1.22 0.0812$ $\frac{19^{7}Au(n,p)^{198}Au 7.825E+04 0.0507 1.22 0.0832}{1^{15}In(n,p)^{116m}} 5.176E+03 0.0297 0.99 0.0698$ free field $\frac{5^{5}Fe(n,p)^{56}Mn + 5^{5}Mn(n,p)^{24}Na 3.091E+01 0.0277 1.17 0.0760}{5^{8}Ni(n,p)^{56}Co} 7.235E+00 0.0134 1.24 0.0822$ $\frac{19^{7}Au(n,p)^{198}Au 3.091E+01 0.0277 1.17 0.0760}{5^{8}Ni(n,p)^{56}Co} 7.325E+04 0.0314 1.24 0.0828$ $\frac{19^{7}Au(n,p)^{105m}In 3.429E+02 0.0368 1.06 0.1113}{5^{5}Fe(n,p)^{56}Mn + 5^{5}Mn(n,p)^{105m}In 3.429E+02 0.0368 1.06 0.1113}$ scattering box 1 $\frac{5^{6}Fe(n,p)^{56}Mn + 5^{5}Mn(n,p)^{105m}In 3.429E+02 0.0368 1.06 0.1113}{5^{6}Fe(n,p)^{56}Mn + 5^{5}Mn(n,p)^{56}Co} 4.076E-01 0.0152 1.26 0.1323}$ $\frac{Case 4}{1^{15}In(n,p)^{115m}In 3.429E+02 0.0368 1.06 0.1113}{5^{6}Fe(n,p)^{56}Mn + 5^{5}Mn(n,p)^{56}Co} 4.076E-01 0.0152 1.26 0.1323}$ $\frac{Case 5}{1^{19}Au(n,p)^{198}Au} 3.285E+04 0.0161 1.25 0.0749}{5^{19}Au(n,p)^{198}Au} 3.285E+04 0.0161 1.25 0.0749}$ $\frac{5^{9}Co(n,p)^{60}Co}{3.521E+01} 0.0161 1.25 0.0749}{5^{19}Au(n,p)^{198}Au} 3.285E+04 0.0163 1.27 0.0717}{5^{19}Au(n,p)^{198}Au} 3.285E+04 0.0161 1.25 0.0779}$ scattering box 3 $\frac{5^{10}Co(n,p)^{60}Co}{5.479E+01} 0.0287 1.20 0.0776}{5^{19}Au(n,p)^{198}Au} 3.285E+04 0.0163 1.27 0.0717}{5^{19}Au(n,p)^{198}Au} 4.889E+04 0.0357 1.25 0.0779}$ scattering box 3 $\frac{5^{10}Co(n,p)^{60}Co}{5.479E+01} 0.02277 1.20 0.0776}{5^{19}Au(n,p)^{198}Au} 4.889E+04 0.0357 1.25 0.0779}$		Case 1	¹¹⁵ In(n,n'γ) ^{115m} In	5.761E+03	0.0188	0.94	0.0661	
$\begin{array}{c c c c c c c c c c c c c c c c c c c $		collimator A	⁵⁶ Fe(n,p) ⁵⁶ Mn + ⁵⁵ Mn(n,γ) ⁵⁶ Mn	2.297E+03	0.0317	1.14	0.0759	
$ \begin{array}{c} \frac{58}{9} N(n,p)^{58} Co & 7.818E+00 & 0.0166 & 1.14 & 0.0657 \\ \frac{59}{9} Co(n,\gamma)^{60} Co & 3.883E+01 & 0.0033 & 1.20 & 0.0784 \\ \frac{197}{9} Au(n,\gamma)^{19} Au & 3.883E+04 & 0.0041 & 1.25 & 0.0831 \\ \frac{113}{11} (n,\gamma)^{116} m1 & 4.690E+06 & 0.0035 & 1.22 & 0.0842 \\ collimator B & \frac{56}{9} Fe(n,p)^{50} Mn & 1.257E+03 & 0.0033 & 1.21 & 0.0741 \\ \frac{24}{9} Mg(n,p)^{24} Na & 6.949E+00 & 0.0151 & 1.26 & 0.1196 \\ \frac{58}{9} Ni(n,p)^{58} Co & 1.475E+00 & 0.0077 & 1.16 & 0.1120 \\ \frac{59}{9} Co(n,\gamma)^{60} Co & 7.641E+01 & 0.0409 & 1.22 & 0.0812 \\ \frac{197}{4} Nu(n,\gamma)^{16} Ma & 8.874E+06 & 0.0414 & 1.13 & 0.0822 \\ \frac{115}{11} (n,n'\gamma)^{115m} In & 5.176E+03 & 0.0297 & 0.99 & 0.0698 \\ free field & \frac{56}{9} Fe(n,p)^{50} Mn & 2.560E+03 & 0.0383 & 1.23 & 0.0749 \\ \frac{24}{4} Mg(n,p)^{24} Na & 3.091E+01 & 0.0277 & 1.17 & 0.0760 \\ \frac{58}{5} N(n,p)^{58} Co & 7.235E+00 & 0.0209 & 1.14 & 0.0667 \\ \frac{59}{2} Co(n,\gamma)^{60} Co & 3.026E+01 & 0.0376 & 1.24 & 0.0828 \\ 115} In(n,n'\gamma)^{115m} In & 3.429E+02 & 0.0368 & 1.06 & 0.1113 \\ scattering box 1 & \frac{56}{9} Fe(n,p)^{50} Mn + \frac{55}{5} N(n,\gamma)^{56} Ch & 3.521E+00 & 0.0414 & 1.26 & 0.0852 \\ \frac{197}{4} Mg(n,p)^{24} Na & 2.987E+04 & 0.0314 & 1.26 & 0.0852 \\ \frac{197}{4} Mg(n,\gamma)^{125m} In & 3.429E+02 & 0.0368 & 1.06 & 0.1113 \\ \frac{58}{9} N(n,\gamma)^{58} Co & 4.076E-01 & 0.0152 & 1.26 & 0.1323 \\ \frac{Case 5}{8} N(n,p)^{58} Co & 3.521E+01 & 0.0161 & 1.25 & 0.0749 \\ \frac{58}{10} (n,n\gamma)^{16} Mn + \frac{3.548E+04}{3.285E+04} & 0.0143 & 1.20 & 0.1358 \\ \frac{58}{10} (n,n\gamma)^{58} Au & 3.285E+04 & 0.0163 & 1.27 & 0.0774 \\ \frac{58}{10} (n,n\gamma)^{168} Au & 3.285E+04 & 0.0163 & 1.27 & 0.0774 \\ \frac{59}{197} Au(n,\gamma)^{198} Au & 3.285E+04 & 0.0163 & 1.27 & 0.0774 \\ \frac{59}{197} Au(n,\gamma)^{198} Au & 3.285E+04 & 0.0163 & 1.27 & 0.0774 \\ \frac{59}{197} Au(n,\gamma)^{198} Au & 3.285E+04 & 0.0163 & 1.27 & 0.0774 \\ \frac{59}{197} Au(n,\gamma)^{198} Au & 3.285E+04 & 0.0163 & 1.27 & 0.0774 \\ \frac{59}{197} Au(n,\gamma)^{198} Au & 3.285E+04 & 0.0163 & 1.27 & 0.0774 \\ \frac{59}{197} Au(n,\gamma)^{198} Au & 3.285E+04 & 0.0287 & 1.20 & 0.0776 \\ \frac{59}{197} Au(n,\gamma)^{198} Au & 3.285E+04 & 0.0277 & 1.20 & 0.0776 $			²⁴ Mg(n,p) ²⁴ Na	3.367E+01	0.0229	1.36	0.0686	
$\begin{array}{c} & \frac{59}{9} \text{Co}(n,\gamma)^{60} \text{Co} & 3.883 \text{E}+01 & 0.0033 & 1.20 & 0.0784 \\ 19^{9} \text{Au}(n,\gamma)^{198} \text{Au} & 3.883 \text{E}+04 & 0.0041 & 1.25 & 0.0831 \\ 11^{51} \ln(n,\gamma)^{115} \text{m} n & 9.600 \text{E}+02 & 0.0071 & 1.02 & 0.1076 \\ \hline \text{collimator B} & \frac{56}{9} \text{Fe}(n,p)^{56} \text{Mn} + \\ & \frac{55}{9} \text{Mn}(n,\gamma)^{56} \text{Mn} & 1.257 \text{E}+03 & 0.0033 & 1.21 & 0.0741 \\ & \frac{24}{Mg}(n,p)^{24} \text{Na} & 6.949 \text{E}+00 & 0.0151 & 1.26 & 0.1196 \\ & \frac{58}{9} \text{Ni}(n,p)^{58} \text{Co} & 1.475 \text{E}+00 & 0.0077 & 1.16 & 0.1120 \\ & \frac{59}{7} \text{Co}(n,\gamma)^{60} \text{Co} & 7.641 \text{E}+01 & 0.0409 & 1.22 & 0.0812 \\ & 19^{7} \text{Au}(n,\gamma)^{198} \text{Au} & 7.825 \text{E}+04 & 0.0507 & 1.22 & 0.0832 \\ & 11^{5} \ln(n,n')^{116} \text{m} & 8.874 \text{E}+06 & 0.0414 & 1.13 & 0.0822 \\ & \frac{115} \ln(n,n')^{116} \text{m} & 5.176 \text{E}+03 & 0.0297 & 0.99 & 0.0698 \\ & \frac{56}{7} \text{Fe}(n,p)^{56} \text{Mn} + \\ & \frac{55}{9} \text{Mn}(n,\gamma)^{56} \text{Mn} & 2.560 \text{E}+03 & 0.0383 & 1.23 & 0.0749 \\ & \frac{24}{Mg}(n,p)^{24} \text{Na} & 3.091 \text{E}+01 & 0.0277 & 1.17 & 0.0760 \\ & \frac{59}{9} \text{Co}(n,\gamma)^{60} \text{Co} & 3.026 \text{E}+01 & 0.0376 & 1.24 & 0.0828 \\ & \frac{19^{7} \text{Au}(n,\gamma)^{198} \text{Au} & 2.987 \text{E}+04 & 0.0314 & 1.24 & 0.0776 \\ & \frac{19^{7} \text{Au}(n,\gamma)^{198} \text{Au} & 2.987 \text{E}+04 & 0.0314 & 1.24 & 0.0776 \\ & \frac{19^{7} \text{Au}(n,\gamma)^{198} \text{Au} & 2.987 \text{E}+04 & 0.0314 & 1.24 & 0.0776 \\ & \frac{19^{7} \text{Au}(n,\gamma)^{198} \text{Au} & 2.987 \text{E}+04 & 0.0314 & 1.24 & 0.0776 \\ & \frac{19^{7} \text{Au}(n,\gamma)^{198} \text{Au} & 2.987 \text{E}+04 & 0.0314 & 1.24 & 0.0776 \\ & \frac{19^{7} \text{Au}(n,\gamma)^{198} \text{Au} & 2.987 \text{E}+04 & 0.0314 & 1.24 & 0.0776 \\ & \frac{19^{7} \text{Au}(n,\gamma)^{198} \text{Au} & 2.987 \text{E}+04 & 0.0314 & 1.24 & 0.0776 \\ & \frac{59}{9} \text{Co}(n,\gamma)^{60} \text{Co} & 3.521 \text{E}+01 & 0.0161 & 1.25 & 0.0749 \\ & \frac{24}{Mg}(n,p)^{24} \text{Na} & 1.451 \text{E}+00 & 0.0143 & 1.20 & 0.1358 \\ & \frac{58}{8} \text{Ni}(n,p)^{58} \text{Co} & 2.528 \text{E}+04 & 0.0163 & 1.27 & 0.0717 \\ & \frac{58}{8} \text{Ni}(n,p)^{58} \text{Co} & 2.578 \text{E}+04 & 0.0163 & 1.27 & 0.0717 \\ & \frac{59}{9} \text{Co}(n,\gamma)^{60} \text{Co} & 5.479 \text{E}+01 & 0.0287 & 1.20 & 0.0774 \\ & \frac{59}{9} \text{Co}(n,\gamma)^{60} \text{Co} & 5.479 \text{E}+01 & 0.0237 & 1.20 & 0.0776 $			58Ni(n,p)58Co	7.818E+00	0.0166	1.14	0.0657	
$\begin{array}{c} & \begin{array}{c} & \end{array} \\ \\ & \end{array} \\ \\ & \begin{array}{c} & \end{array} \\ \\ & \begin{array}{c} & \end{array} \\ \\ & \end{array} \\ \\ \end{array} \\ \\ \end{array} \\ \\ \end{array} \\ \end{array} \\ \\ \end{array} \\ \end{array}$	ľ		⁵⁹ Co(n,γ) ⁶⁰ Co	3.883E+01	0.0033	1.20	0.0784	1
$\begin{array}{c} \begin{array}{c} \text{Case 2} & \overset{115}{15} \text{In}(n,n^{+})^{115} \text{In}}{\text{In}} & 4.690 \text{E} + 06 & 0.0035 & 1.22 & 0.0842 \\ \text{collimator B} & \overset{56}{5} \text{Fe}(n,p)^{56} \text{Mn} + & 9.600 \text{E} + 02 & 0.0071 & 1.02 & 0.1076 \\ & \overset{56}{5} \text{Mn}(n,\gamma)^{56} \text{Mn} + & 1.257 \text{E} + 03 & 0.0033 & 1.21 & 0.0741 \\ & \overset{24}{10} \text{g}(n,p)^{24} \text{Na} & 6.949 \text{E} + 00 & 0.0151 & 1.26 & 0.1196 \\ & \overset{58}{5} \text{Ni}(n,p)^{58} \text{Co} & 1.475 \text{E} + 00 & 0.0077 & 1.16 & 0.1120 \\ & \overset{59}{2} \text{Co}(n,\gamma)^{60} \text{Co} & 7.641 \text{E} + 01 & 0.0409 & 1.22 & 0.0812 \\ & \overset{115}{10} \text{In}(n,\gamma)^{116} \text{In} & 8.874 \text{E} + 06 & 0.0014 & 1.13 & 0.0822 \\ & \overset{115}{10} \text{In}(n,\gamma)^{116} \text{In} & 8.874 \text{E} + 06 & 0.0414 & 1.13 & 0.0822 \\ & \overset{115}{116} \text{In}(n,\gamma)^{115} \text{In} \text{In} & 5.176 \text{E} + 03 & 0.0297 & 0.99 & 0.0698 \\ \end{array}$			$^{197}Au(n,\gamma)^{198}Au$	3.883E+04	0.0041	1.25	0.0831	
$\begin{array}{c} \text{Case 2} & \overset{115}{\text{In}(n,n'\gamma)^{115\text{m}In}}{\text{S}^{6}\text{Fe}(n,p)^{56}\text{Mn}} + \overset{55\text{Mn}(n,\gamma)^{56}\text{Mn}}{1.257\text{E}+03} & 0.0033 & 1.21 & 0.0741 \\ & \overset{56\text{Fe}(n,p)^{56}\text{Mn}}{2^4\text{Mg}(n,p)^{24}\text{Na}} & 6.949\text{E}+00 & 0.0151 & 1.26 & 0.1196 \\ & \overset{58\text{Ni}(n,p)^{56}\text{Co}}{1.475\text{E}+00} & 0.0077 & 1.16 & 0.1120 \\ & \overset{59\text{Co}(n,\gamma)^{60}\text{Co}}{7.641\text{E}+01} & 0.0409 & 1.22 & 0.0812 \\ & \overset{197}{197}\text{Au}(n,\gamma)^{198}\text{Au} & 7.825\text{E}+04 & 0.0507 & 1.22 & 0.0832 \\ & \overset{115}{11n}(n,n'\gamma)^{115\text{m}In} & 5.176\text{E}+03 & 0.0297 & 0.99 & 0.0698 \\ & \overset{56\text{Fe}(n,p)^{56}\text{Mn}}{5^5\text{Fe}(n,p)^{56}\text{Mn}} & 2.560\text{E}+03 & 0.0383 & 1.23 & 0.0749 \\ & \overset{24\text{Mg}(n,p)^{24}\text{Na}}{3.091\text{E}+01} & 0.0277 & 1.17 & 0.0760 \\ & \overset{58\text{Ni}(n,p)^{58}\text{Co}}{7.235\text{E}+00} & 0.0209 & 1.14 & 0.0667 \\ & \overset{197}{2^4\text{Mg}(n,p)^{24}\text{Na}} & 3.091\text{E}+01 & 0.0277 & 1.17 & 0.0760 \\ & \overset{58\text{Ni}(n,p)^{58}\text{Co}}{7.235\text{E}+00} & 0.0383 & 1.24 & 0.0828 \\ & \overset{197}{197}\text{Au}(n,\gamma)^{198}\text{Au} & 2.987\text{E}+04 & 0.0314 & 1.24 & 0.0828 \\ & \overset{197}{197}\text{Au}(n,\gamma)^{198}\text{Au} & 2.987\text{E}+04 & 0.0314 & 1.24 & 0.0776 \\ & \overset{115}{11n}(n,n'\gamma)^{115\text{m}In} & 3.429\text{E}+02 & 0.0368 & 1.06 & 0.1113 \\ & \overset{56\text{Fe}(n,p)^{56}\text{Mn} + \\ & \overset{55\text{Ni}(n,p)^{58}\text{Co} & 3.521\text{E}+01 & 0.0161 & 1.25 & 0.0749 \\ & \overset{24\text{Mg}(n,p)^{24}\text{Na} & 1.451\text{E}+00 & 0.0143 & 1.20 & 0.1328 \\ & \overset{58\text{Ni}(n,p)^{58}\text{Co} & 3.521\text{E}+01 & 0.0161 & 1.25 & 0.0749 \\ & \overset{24\text{Mg}(n,p)^{24}\text{Na} & 3.285\text{E}+04 & 0.0163 & 1.27 & 0.0717 \\ & \overset{58\text{Ni}(n,p)^{58}\text{Co} & 2.128\text{E}-01 & 0.0161 & 1.25 & 0.07749 \\ & \overset{58\text{Ni}(n,p)^{58}\text{Co} & 5.479\text{E}+01 & 0.0287 & 1.20 & 0.0776 \\ & \overset{58\text{Ni}(n,p)^{58}\text{Co} & 7.67\text{E}+00 & 0.0301 & 1.01 & 0.0776 \\ & \overset{58\text{Ni}(n,p)^{58}\text{Co} & 1.767\text{E}+00 & 0.0301 & 1.01 & 0.0776 \\ & \overset{58\text{Ni}(n,p)^{58}\text{Co} & 1.767\text{E}+00 & 0.0301 & 1.01 & 0.0776 \\ & \overset{58\text{Ni}(n,p)^{58}\text{Co} & 1.787\text{E}+00 & 0.0426 & 0.98 & 0.0839 \\ \end{array}}$			115 In $(n,\gamma)^{116}$ In	4.690E+06	0.0035	1.22	0.0842	
$ \begin{array}{c} \mbox{collimator B} & {}^{56}\mbox{Fe}(n,p){}^{56}\mbox{Mn} + \\ {}^{58}\mbox{Mn}(n,\gamma){}^{59}\mbox{Mn} + \\ {}^{24}\mbox{Mg}(n,p){}^{24}\mbox{Na} & 6.949\mbox{E}+00 & 0.0151 & 1.26 & 0.1196 \\ {}^{58}\mbox{Ni}(n,p){}^{58}\mbox{Co} & 1.475\mbox{E}+00 & 0.0077 & 1.16 & 0.1120 \\ \\ {}^{59}\mbox{Co}(n,\gamma){}^{60}\mbox{Co} & 1.475\mbox{E}+01 & 0.0409 & 1.22 & 0.0812 \\ {}^{197}\mbox{Au}(n,\gamma){}^{198}\mbox{Au} & 7.825\mbox{E}+04 & 0.0507 & 1.22 & 0.0832 \\ \\ {}^{115}\mbox{In}(n,n'){}^{116}\mbox{In} & 8.874\mbox{E}+06 & 0.0414 & 1.13 & 0.0822 \\ \\ {}^{115}\mbox{In}(n,\gamma){}^{116}\mbox{In} & 8.874\mbox{E}+06 & 0.0297 & 0.99 & 0.0698 \\ \\ {}^{56}\mbox{Fe}(n,p){}^{56}\mbox{Mn} + \\ {}^{56}\mbox{Mn}(n,\gamma){}^{56}\mbox{Mn} + \\ {}^{56}\mbox{Mn}(n,\gamma){}^{56}\mbox{Mn} + \\ {}^{56}\mbox{Mn}(n,\gamma){}^{56}\mbox{Mn} + \\ {}^{24}\mbox{Mg}(n,p){}^{24}\mbox{Na} & 3.091\mbox{E}+01 & 0.0277 & 1.17 & 0.0760 \\ \\ {}^{58}\mbox{Ni}(n,p){}^{58}\mbox{Co} & 7.235\mbox{E}+00 & 0.0338 & 1.23 & 0.0749 \\ {}^{24}\mbox{Mg}(n,p){}^{24}\mbox{Na} & 2.987\mbox{E}+04 & 0.0314 & 1.24 & 0.0828 \\ \\ \\ {}^{197}\mbox{Au}(n,\gamma){}^{198}\mbox{Au} & 2.987\mbox{E}+04 & 0.0314 & 1.24 & 0.0776 \\ \\ \\ {}^{115}\mbox{In}(n,\gamma){}^{16}\mbox{Mn} + \\ {}^{56}\mbox{Nn}(n,\gamma){}^{56}\mbox{Mn} + \\ \\ \\ {}^{56}\mbox{Nn}(n,\gamma){}^{56}\mbox{Mn} + \\ \\ \\ {}^{56}\mbox{Nn}(n,\gamma){}^{56}\mbox{Mn} + \\ \\ \\ \\ {}^{56}\mbox{Nn}(n,\gamma){}^{56}\mbox{Mn} + \\ \\ \\ \\ \\ {}^{56}\mbox{Nn}(n,\gamma){}^{56}\mbox{Mn} + \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ \\ $		Case 2	$^{115}In(n,n'\gamma)^{115m}In$	9.600E+02	0.0071	1.02	0.1076	
$ \begin{array}{c} \begin{array}{c} \begin{array}{c} & \end{array} \\ & \begin{array}{c} & \end{array} \\ & \begin{array}{c} & \end{array} \\ & \begin{array}{c} & \begin{array}{c} & \begin{array}{c} & \begin{array}{c} & \begin{array}{c} & \begin{array}{c} & \end{array} \\ & \end{array} \\ \\ & \begin{array}{c} & \end{array} \\ & \begin{array}{c} & \end{array} \\ & \begin{array}{c} & \end{array} \\ & \end{array} \\ \\ & \begin{array}{c} & \end{array} \\ & \end{array} \\ \\ & \begin{array}{c} & \end{array} \\ & \begin{array}{c} & \end{array} \\ & \begin{array}{c} & \end{array} \\ & \end{array} \\ & \begin{array}{c} & \end{array} \\ & \begin{array}{c} & \end{array} \\ & \end{array} \\ \\ & \begin{array}{c} & \end{array} \\ & \end{array} \\ & \begin{array}{c} & \end{array} \\ & \begin{array}{c} & \end{array} \\ & \end{array} \\ \\ & \begin{array}{c} & \end{array} \\ \\ & \end{array} \\ \\ & \begin{array}{c} & \end{array} \\ \\ & \end{array} \\ \\ & \begin{array}{c} & \end{array} \\ & \end{array} \\ \\ & \begin{array}{c} & \end{array} \\ \\ & \begin{array}{c} & \end{array} \\ \\ & \end{array} \\ \\ & \begin{array}{c} & \end{array} \\ & \end{array} \\ \\ & \begin{array}{c} & \end{array} \\ \\ & \end{array} \\ \\ & \begin{array}{c} & \end{array} \\ & \end{array} \\ \\ & \end{array} \\ \\ & \begin{array}{c} & \end{array} \\ \\ & \end{array} \\ \\ & \end{array} \\ \\ \\ & \begin{array}{c} & \end{array} \\ \\ & \end{array} \\ \\ & \end{array} \\ \\ \\ & \end{array} \\ \\ & \end{array} \\ \\ \\ \\$		collimator B	56 Fe(n,p) 56 Mn + 55 Mn(n, γ) 56 Mn	1.257E+03	0.0033	1.21	0.0741	
$ \begin{array}{c} \frac{5^{8}\text{Ni}(n,p)^{58}\text{Co} & 1.475\text{E}+00 & 0.0077 & 1.16 & 0.1120 \\ \frac{5^{9}\text{Co}(n,\gamma)^{60}\text{Co} & 7.641\text{E}+01 & 0.0409 & 1.22 & 0.0812 \\ 1^{197}\text{Au}(n,\gamma)^{198}\text{Au} & 7.825\text{E}+04 & 0.0507 & 1.22 & 0.0832 \\ \frac{115}\ln(n,\gamma)^{116}\ln & 8.874\text{E}+06 & 0.0414 & 1.13 & 0.0822 \\ 1^{15}\ln(n,\gamma)^{115}\text{mIn} & 5.176\text{E}+03 & 0.0297 & 0.99 & 0.0698 \\ \hline \text{free field} & \frac{5^{6}\text{Fe}(n,p)^{56}\text{Mn} + }{5^{5}\text{Mn}(n,\gamma)^{56}\text{Mn}} & 2.560\text{E}+03 & 0.0383 & 1.23 & 0.0749 \\ \frac{2^{4}\text{Mg}(n,p)^{24}\text{Na} & 3.091\text{E}+01 & 0.0277 & 1.17 & 0.0760 \\ & \frac{5^{8}\text{Ni}(n,p)^{58}\text{Co} & 7.235\text{E}+00 & 0.0209 & 1.14 & 0.0667 \\ \hline & \frac{5^{9}\text{Co}(n,\gamma)^{60}\text{Co} & 3.026\text{E}+01 & 0.0376 & 1.24 & 0.0828 \\ 1^{197}\text{Au}(n,\gamma)^{198}\text{Au} & 2.987\text{E}+04 & 0.0314 & 1.24 & 0.0776 \\ \hline & \frac{1^{15}\ln(n,\gamma)^{116}\ln}{3.653\text{E}+06} & 0.0413 & 1.26 & 0.0852 \\ \hline & \frac{1^{15}\ln(n,\gamma)^{116}\text{In}}{5^{6}\text{M}(n,\gamma)^{56}\text{Mn}} & 1.51\text{E}+03 & 0.0470 & 1.31 & 0.0820 \\ \hline & \frac{2^{4}\text{Mg}(n,p)^{24}\text{Na} & 1.451\text{E}+00 & 0.0143 & 1.20 & 0.1358 \\ \hline & \frac{5^{8}\text{Ni}(n,p)^{58}\text{Co} & 4.076\text{E}-01 & 0.0152 & 1.26 & 0.1323 \\ \hline & \frac{5^{8}\text{Ni}(n,p)^{58}\text{Co} & 2.128\text{E}-01 & 0.0318 & 1.12 & 0.1776 \\ \hline & \frac{1^{57}\text{Au}(n,\gamma)^{198}\text{Au} & 3.285\text{E}+04 & 0.0163 & 1.27 & 0.0717 \\ \hline & \frac{5^{9}\text{Co}(n,\gamma)^{60}\text{Co} & 5.479\text{E}+01 & 0.0287 & 1.20 & 0.0774 \\ \hline & \frac{5^{9}\text{Co}(n,\gamma)^{60}\text{Co} & 5.478\text{E}+04 & 0.0309 & 1.24 & 0.0753 \\ \hline & \frac{5^{9}\text{Co}(n,\gamma)^{60}\text{Co} & 5.478\text{E}+04 & 0.0309 & 1.24 & 0.0753 \\ \hline & \frac{5^{9}\text{Co}(n,\gamma)^{60}\text{Co} & 4.946\text{E}+01 & 0.0270 & 1.20 & 0.0776 \\ \hline & \frac{5^{9}\text{Co}(n,\gamma)^{60}\text{Co} & 4.946\text{E}+01 & 0.0270 & 1.20 & 0.0776 \\ \hline & \frac{5^{9}\text{Co}(n,\gamma)^{60}\text{Co} & 4.946\text{E}+01 & 0.0270 & 1.20 & 0.0776 \\ \hline & \frac{5^{9}\text{Co}(n,\gamma)^{198}\text{Au} & 4.889\text{E}+04 & 0.0357 & 1.25 & 0.0779 \\ \hline & \frac{5^{8}\text{Ni}(n,p)^{58}\text{Co} & 1.787\text{E}+00 & 0.0426 & 0.98 & 0.0839 \\ \hline \end{array}$	S)	$^{24}Mg(n,p)^{24}Na$	6.949E+00	0.0151	1.26	0.1196	
$ \begin{array}{c} \begin{array}{c} \frac{59}{2} \text{Co}(\mathbf{n}, \gamma)^{60} \text{Co} & 7.641 \text{E}+01 & 0.0409 & 1.22 & 0.0812 \\ \frac{197}{4} \text{Au}(\mathbf{n}, \gamma)^{198} \text{Au} & 7.825 \text{E}+04 & 0.0507 & 1.22 & 0.0832 \\ \frac{115}{1} \ln(\mathbf{n}, \gamma)^{116} \ln & 8.874 \text{E}+06 & 0.0414 & 1.13 & 0.0822 \\ \text{free field} & \frac{56}{5} \text{Fe}(\mathbf{n}, p)^{56} \text{Mn} + \\ \frac{55}{5} \text{Mn}(\mathbf{n}, \gamma)^{56} \text{Mn} + \\ \frac{55}{5} \text{Mn}(\mathbf{n}, \gamma)^{56} \text{Mn} + \\ \frac{24}{3} \text{Mg}(\mathbf{n}, p)^{24} \text{Na} & 3.091 \text{E}+01 & 0.0277 & 1.17 & 0.0760 \\ \hline & 2^{4} \text{Mg}(\mathbf{n}, p)^{58} \text{Co} & 7.235 \text{E}+00 & 0.0209 & 1.14 & 0.0667 \\ \hline & \frac{59}{2} \text{Co}(\mathbf{n}, \gamma)^{60} \text{Co} & 3.026 \text{E}+01 & 0.0376 & 1.24 & 0.0828 \\ \hline & 19^{7} \text{Au}(\mathbf{n}, \gamma)^{198} \text{Au} & 2.987 \text{E}+04 & 0.0314 & 1.24 & 0.0776 \\ \hline & \frac{197}{4} \text{Au}(\mathbf{n}, \gamma)^{198} \text{Mn} + \\ 3.653 \text{E}+06 & 0.0341 & 1.26 & 0.0852 \\ \hline & \frac{197}{4} \text{Mg}(\mathbf{n}, p)^{56} \text{Mn} + \\ \frac{55}{5} \text{Mn}(\mathbf{n}, \gamma)^{56} \text{Mn} + \\ \frac{55}{5} \text{Nn}(\mathbf{n}, \gamma)^{56} \text{Mn} + \\ \frac{56}{5} \text{Nn}(\mathbf{n}, \gamma)^{56} \text{Mn} + \\ \frac{55}{5} \text{Nn}(\mathbf{n}, \gamma)^{56} \text{Mn} + \\ \frac{56}{5} \text{Nn}(\mathbf{n}, \gamma)^{56} \text{Mn} + \\ \frac{55}{5} \text{Nn}(\mathbf{n}, \gamma)^{58} \text{Co} & 3.521 \text{E}+01 & 0.0161 & 1.25 & 0.0749 \\ \frac{59}{2} \text{Co}(\mathbf{n}, \gamma)^{60} \text{Co} & 3.521 \text{E}+01 & 0.0161 & 1.25 & 0.0749 \\ \frac{59}{197} \text{Au}(\mathbf{n}, \gamma)^{198} \text{Au} & 3.285 \text{E}+04 & 0.0163 & 1.27 & 0.0717 \\ \frac{59}{5} \text{Nn}(\mathbf{n}, \gamma)^{58} \text{Co} & 1.767 \text{E}+00 & 0.0301 & 1.01 & 0.0776 \\ \frac{59}{2} \text{Co}(\mathbf{n}, \gamma)^{60} \text{Co} & 5.479 \text{E}+01 & 0.0287 & 1.20 & 0.0774 \\ \frac{59}{2} \text{Nu}(\mathbf{n}, \gamma)^{198} \text{Au} & 4.889 \text{E}+04 & 0.0357 & 1.25 & 0.0779 \\ \frac{59}{5} \text{Nn}(\mathbf{n}, \gamma)^{58} \text{Co} & 1.787 \text{E}+00 & 0.0426 & 0.98 & 0.0839 \\ \end{array}}$			58Ni(n,p)58Co	1.475E+00	0.0077	1.16	0.1120	
$\begin{array}{c} \begin{array}{c} & \end{array} \\ & \begin{array}{c} & \begin{array}{c} & \begin{array}{c} & \end{array} \\ & \end{array} \\ & \begin{array}{c} & \end{array} \\ & \end{array} \\ & \begin{array}{c} & \end{array} \\ & \begin{array}{c} & \end{array} \\ & \end{array} \\ & \begin{array}{c} & \end{array} \\ & \end{array} \\ & \begin{array}{c} & \end{array} \\ & \begin{array}{c} & \end{array} \\ & \end{array} \\ & \begin{array}{c} & \end{array} \\ & \begin{array}{c} & \end{array} \\ & \end{array} \\ & \begin{array}{c} & \end{array} \\ & \end{array} \\ & \begin{array}{c} & \end{array} \\ & \begin{array}{c} & \end{array} \\ & \begin{array}{c} & \end{array} \\ & \end{array} \\ \\ & \begin{array}{c} & \end{array} \\ & \end{array} \\ \\ & \begin{array}{c} & \end{array} \\ & \end{array} \\ \\ & \begin{array}{c} & \end{array} \\ & \begin{array}{c} & \end{array} \\ & \end{array} \\ & \begin{array}{c} & \end{array} \\ & \end{array} \\ & \begin{array}{c} & \end{array} \\ & \begin{array}{c} & \end{array} \\ & \end{array} \\ & \begin{array}{c} & \end{array} \\ & \end{array} \\ \\ & \begin{array}{c} & \end{array} \\ & \end{array} \\ & \begin{array}{c} & \end{array} \\ & \end{array} \\ \\ & \begin{array}{c} & \end{array} \\ & \end{array} \\ \\ & \end{array} \\ \\ & \end{array} \\ \\ & \begin{array}{c} & \end{array} \\ & \end{array} \\ \\ & \end{array} \\ \\ & \begin{array}{c} & \end{array} \\ & \end{array} \\ \\ & \end{array} \\ \\ & \end{array} \\ \\ & \begin{array}{c} & \end{array} \\ & \end{array} \\ & \end{array} \\ \\ \\ & \end{array} \\ \\ & \end{array} \\ \\ \\ & \end{array} \\ \\ \\ \\$	ľ		⁵⁹ Co(n, γ) ⁶⁰ Co	7.641E+01	0.0409	1.22	0.0812	1
$\begin{array}{c} \begin{array}{c} \begin{array}{c} \text{Case 3} \\ \text{free field} \end{array} & \stackrel{115}{5} \text{In}(n,\gamma)^{116} \text{In} \\ \stackrel{56}{5} \text{Fe}(n,p)^{56} \text{Mn} + \\ \stackrel{55}{5} \text{Mn}(n,\gamma)^{56} \text{Mn} \\ \stackrel{24}{5} \text{Mg}(n,p)^{24} \text{Na} \\ \stackrel{24}{5} \text{Mg}(n,p)^{24} \text{Na} \\ \stackrel{24}{5} \text{Mg}(n,p)^{24} \text{Na} \\ \stackrel{24}{5} \text{Mg}(n,p)^{24} \text{Na} \\ \stackrel{24}{5} \text{Mg}(n,p)^{56} \text{Co} \\ \stackrel{7.235 \text{E}+00}{7.235 \text{E}+00} \\ \stackrel{0.0209}{0.0209} \\ \stackrel{1.14}{1.17} \\ \stackrel{0.0760}{0.0209} \\ \stackrel{1.14}{1.14} \\ \stackrel{0.0667}{0.0067} \\ \stackrel{107}{4} \text{u}(n,\gamma)^{198} \text{Au} \\ \stackrel{2.987 \text{E}+04}{2.987 \text{E}+04} \\ \stackrel{0.0314}{0.0314} \\ \stackrel{1.26}{1.24} \\ \stackrel{0.0376}{0.0852} \\ \stackrel{105}{1.16} \text{In}(n,\gamma)^{115m} \text{In} \\ \stackrel{3.653 \text{E}+06}{3.632 \text{E}+02} \\ \stackrel{0.0368}{0.0341} \\ \stackrel{1.26}{1.26} \\ \stackrel{0.0820}{0.0852} \\ \stackrel{105}{1.5} \text{In}(n,\gamma)^{56} \text{Mn} \\ \stackrel{1.55 \text{Mn}(n,\gamma)^{56} \text{Mn} \\ \stackrel{2.4 \text{Mg}(n,p)^{24} \text{Na} \\ \stackrel{1.45 \text{E}+03}{5} \\ \stackrel{0.0470}{0.0470} \\ \stackrel{1.31}{1.31} \\ \stackrel{0.0820}{0.0820} \\ \stackrel{24}{24} \\ \stackrel{1.55 \text{Mn}(n,\gamma)^{56} \text{Mn} \\ \stackrel{24}{55} \\ \stackrel{1.55 \text{Mn}(n,\gamma)^{56} \text{Mn} \\ \stackrel{24}{1.51 \text{E}+03} \\ \stackrel{0.0470}{0.0470} \\ \stackrel{1.31}{1.31} \\ \stackrel{0.0820}{0.0820} \\ \stackrel{24}{24} \\ \stackrel{1.58 \text{Ni}(n,p)^{58} \text{Co} \\ \stackrel{1.45 \text{E}+01}{0.0161} \\ \stackrel{0.125}{1.26} \\ \stackrel{0.1323}{0.0749} \\ \stackrel{197}{4} \\ \stackrel{107}{4} \\ \stackrel{107}{4} \\ \stackrel{10}{4} \\ \stackrel{10}{1.51 \text{E}+03} \\ \stackrel{0.0470}{0.0153} \\ \stackrel{1.27}{1.20} \\ \stackrel{0.0717}{0.0717} \\ \stackrel{107}{58 \text{Ni}(n,p)^{58} \text{Co} \\ \stackrel{2.128 \text{E}-01}{0.0318} \\ \stackrel{1.12}{1.12} \\ \stackrel{0.0774}{0.0774} \\ \stackrel{107}{4} \\ \stackrel{107}{4} \\ \stackrel{10}{1.798} \text{Au} \\ \stackrel{5.436 \text{E}+04}{0.0309} \\ \stackrel{0.24}{1.24} \\ \stackrel{0.0753}{0.0779} \\ \stackrel{107}{58} \\ \stackrel{107}{6} \\ \stackrel{107}{4} \\ \stackrel{10}{1.798} \\ \stackrel{10}{4} \\ \stackrel{1.898 \text{E}+04}{0.0301} \\ \stackrel{0.0287}{1.20} \\ \stackrel{0.0776}{1.20} \\ \stackrel{0.0776}{0.0776} \\ \stackrel{107}{58} \\ \stackrel{10}{1.01} \\ \stackrel{10}{1.01} \\ \stackrel{0.0776}{0.0776} \\ \stackrel{107}{58} \\ \stackrel{10}{1.01} \\ \stackrel{10}{1.25} \\ \stackrel{10}{1.$			$^{197}Au(n,\gamma)^{198}Au$	7.825E+04	0.0507	1.22	0.0832	
$\begin{array}{c} \text{Case 3} & \overset{115}{\text{free field}} & \overset{115}{\text{Fe}(n,p)^{56}\text{Mn}}{}^{56}\text{Fe}(n,p)^{56}\text{Mn} + \\ & \overset{55}{\text{55}\text{Mn}(n,\gamma)^{56}\text{Mn}}{}^{24}\text{Mg}(n,p)^{24}\text{Na} & 3.091\text{E}+01 & 0.0297 & 0.99 & 0.0698 \\ & \overset{24}{\text{Mg}(n,p)^{24}\text{Na}} & 3.091\text{E}+01 & 0.0277 & 1.17 & 0.0760 \\ & \overset{58}{\text{58}\text{Ni}(n,p)^{58}\text{Co}} & 7.235\text{E}+00 & 0.0209 & 1.14 & 0.0667 \\ & \overset{59}{\text{Co}(n,\gamma)^{60}\text{Co}} & 3.026\text{E}+01 & 0.0376 & 1.24 & 0.0828 \\ & \overset{197}{\text{Au}(n,\gamma)^{198}\text{Au}} & 2.987\text{E}+04 & 0.0314 & 1.24 & 0.0776 \\ & \overset{115}{\text{In}(n,n^{*}\gamma)^{115m}\text{In}} & 3.653\text{E}+06 & 0.0341 & 1.26 & 0.0852 \\ & \overset{115}{\text{In}(n,n^{*}\gamma)^{115m}\text{In}} & 3.429\text{E}+02 & 0.0368 & 1.06 & 0.1113 \\ & \text{scattering box 1} & \overset{56}{\text{56}\text{Fe}(n,p)^{56}\text{Mn}} + \\ & \overset{555}{\text{56}\text{Mn}(n,\gamma)^{56}\text{Mn}} & 1.151\text{E}+03 & 0.0470 & 1.31 & 0.0820 \\ & \overset{24}{\text{Mg}(n,p)^{24}\text{Na}} & 1.451\text{E}+00 & 0.0143 & 1.20 & 0.1358 \\ & \overset{58}{\text{Ni}(n,p)^{56}\text{Co}} & 3.521\text{E}+01 & 0.0161 & 1.25 & 0.0749 \\ & \overset{197}{\text{Au}(n,\gamma)^{198}\text{Au}} & 3.285\text{E}+04 & 0.0163 & 1.27 & 0.0717 \\ & \text{scattering box 2} & \overset{59}{\text{50}\text{Co}(n,\gamma)^{60}\text{Co}} & 5.479\text{E}+01 & 0.0287 & 1.20 & 0.0774 \\ & \overset{59}{\text{58}\text{Ni}(n,p)^{58}\text{Co}} & 1.767\text{E}+00 & 0.0318 & 1.12 & 0.1170 \\ & \overset{59}{\text{58}\text{Ni}(n,p)^{58}\text{Co}} & 1.767\text{E}+00 & 0.0301 & 1.01 & 0.0776 \\ & \overset{59}{\text{58}\text{Ni}(n,p)^{58}\text{Co}} & 1.767\text{E}+00 & 0.0301 & 1.01 & 0.0776 \\ & \overset{59}{\text{58}\text{Ni}(n,p)^{58}\text{Co}} & 1.767\text{E}+00 & 0.0301 & 1.01 & 0.0776 \\ & \overset{59}{\text{58}\text{Ni}(n,p)^{58}\text{Co}} & 1.767\text{E}+00 & 0.0426 & 0.98 & 0.0839 \\ & \overset{58}{\text{Ni}(n,p)^{58}\text{Co}} & 1.787\text{E}+00 & 0.0426 & 0.98 & 0.0839 \\ & \overset{58}{\text{Ni}(n,p)^{58}\text{Co}} & 1.787\text{E}+00 & 0.0426 & 0.98 & 0.0839 \\ & \overset{58}{\text{Ni}(n,p)^{58}\text{Co}} & 1.787\text{E}+00 & 0.0426 & 0.98 & 0.0839 \\ & \overset{58}{\text{Ni}(n,p)^{58}\text{Co}} & 0.787\text{E}+00 & 0.0426 & 0.98 & 0.0839 \\ & \overset{58}{\text{Ni}(n,p)^{58}\text{Co}} & 0.787\text{E}+00 & 0.0426 & 0.98 & 0.0839 \\ & \overset{58}{\text{Ni}(n,p)^{58}\text{Co}} & 0.787\text{E}+00 & 0.0426 & 0.98 & 0.0839 \\ & \overset{58}{\text{Ni}(n,p)^{58}\text{Co}} & 0.787\text{E}+00 & 0.0426 & 0.98 & 0.0839 \\ & \overset{58}{\text{Ni}(n,p)^{58}\text{Co}} & 0.787$			115 In $(n,\gamma)^{116}$ In	8.874E+06	0.0414	1.13	0.0822	
$ \begin{array}{c} \mbox{free field} & {}^{56}\mbox{Fe}(n,p){}^{56}\mbox{Mn} + 2.560\mbox{E}+03 & 0.0383 & 1.23 & 0.0749 \\ {}^{24}\mbox{Mg}(n,p){}^{24}\mbox{Na} & 3.091\mbox{E}+01 & 0.0277 & 1.17 & 0.0760 \\ {}^{58}\mbox{Ni}(n,p){}^{58}\mbox{Co} & 7.235\mbox{E}+00 & 0.0209 & 1.14 & 0.0667 \\ \\ \mbox{Sector}{}^{59}\mbox{Co}(n,\gamma){}^{60}\mbox{Co} & 3.026\mbox{E}+01 & 0.0376 & 1.24 & 0.0828 \\ {}^{197}\mbox{Au}(n,\gamma){}^{198}\mbox{Au} & 2.987\mbox{E}+04 & 0.0314 & 1.24 & 0.0776 \\ \\ \mbox{I}^{15}\mbox{In}(n,\gamma){}^{116}\mbox{In} & 3.653\mbox{E}+06 & 0.0341 & 1.26 & 0.0852 \\ \\ \mbox{Case 4} & {}^{115}\mbox{In}(n,\gamma){}^{116}\mbox{In} & 3.429\mbox{E}+02 & 0.0368 & 1.06 & 0.1113 \\ \\ \mbox{scattering box 1} & {}^{56}\mbox{Fe}(n,p){}^{56}\mbox{Mn} + \\ \\ \mbox{5}{}^{56}\mbox{Mn}(n,\gamma){}^{56}\mbox{Mn} + \\ \\ \mbox{5}{}^{56}\mbox{Nn}(n,\gamma){}^{56}\mbox{Mn} + \\ \\ \mbox{5}{}^{56}\mbox{Co} & 3.521\mbox{E}+01 & 0.0163 & 1.27 & 0.0749 \\ \\ \mbox{5}{}^{59}\mbox{Co}(n,\gamma){}^{60}\mbox{Co} & 5.479\mbox{E}+01 & 0.0287 & 1.20 & 0.0774 \\ \\ \mbox{5}{}^{59}\mbox{Ni}(n,p){}^{58}\mbox{Co} & 1.767\mbox{E}+00 & 0.0318 & 1.12 & 0.1170 \\ \\ \mbox{5}{}^{59}\mbox{Co}(n,\gamma){}^{60}\mbox{Co} & 5.479\mbox{E}+01 & 0.0287 & 1.20 & 0.0774 \\ \\ \mbox{5}{}^{59}\mbox{Co}(n,\gamma){}^{60}\mbox{Co} & 4.94\mbox{E}+04 & 0.0309 & 1.24 & 0.0753 \\ \\ \mbox{5}{}^{59}\mbox{Co}(n,\gamma){}^{60}\mbox{Co} & 4.94\mbox{E}+01 & 0.0270 & 1.20 & 0.0776 \\ \\ \mbox{5}{}^{59}\mbox{Co}(n,\gamma){}^{60}\mbox{Co} & 4.94\mbox{E}+04 & 0.0357 & 1.25 & 0.0779 \\ \\ \mbox{5}{}^{58}\mbox{Ni}(n,p){}^{58}\mbox{Co} & 1.787\mbox{E}+00 & 0.0426 & 0.98 & 0.0839 \\ \end{array} \right)$		Case 3	$^{115}In(n,n'\gamma)^{115m}In$	5.176E+03	0.0297	0.99	0.0698	
$ \begin{array}{c} & \end{array} \\ & \begin{array}{c} & \end{array} \\ & \begin{array}{c} & \end{array} \\ & \begin{array}{c} & \begin{array}{c} & \end{array} \\ & \end{array} \\ & \begin{array}{c} & \end{array} \\ & \end{array} \\ & \begin{array}{c} & \end{array} \\ & \end{array} \\ & \begin{array}{c} & \end{array} \\ & \begin{array}{c} & \end{array} \\ & \end{array} \\ & \begin{array}{c} & \end{array} \\ & \begin{array}{c} & \end{array} \\ & \begin{array}{c} & \end{array} \\ & \end{array} \\ & \begin{array}{c} & \end{array} \\ & \begin{array}{c} & \end{array} \\ & \end{array} \\ & \begin{array}{c} & \end{array} \\ & \end{array} \\ & \begin{array}{c} & \end{array} \\ & \begin{array}{c} & \end{array} \\ & \end{array} \\ & \begin{array}{c} & \end{array} \\ & \end{array} \\ & \begin{array}{c} & \end{array} \\ & \begin{array}{c} & \end{array} \\ & \end{array} \\ & \begin{array}{c} & \end{array} \\ & \begin{array}{c} & \end{array} \\ & \end{array} \\ & \begin{array}{c} & \end{array} \\ & \begin{array}{c} & \end{array} \\ & \end{array} \\ & \begin{array}{c} & \end{array} \\ & \end{array} \\ & \begin{array}{c} & \end{array} \\ & \begin{array}{c} & \end{array} \\ & \end{array} \\ & \end{array} \\ & \end{array} \\ \\ & \end{array} \\ & \end{array} \\ \\ & \end{array} \\ & \end{array} \\ \\ \\ & \end{array} \\ \\ \\ \end{array} \\ \\ \end{array} \\ \\ \\ \end{array} \\ \\ \end{array} \\ \\ \\ \end{array} \\ \\ \end{array} \\ \\ \end{array} \\ \\ \end{array} \\ \\ \\ \end{array} \\ \\ \\ \end{array} \\ $		free field	56 Fe(n,p) 56 Mn + 55 Mn(n, γ) 56 Mn	2.560E+03	0.0383	1.23	0.0749	
$ \begin{array}{c c c c c c c c c c c c c c c c c c c $			$^{24}Mg(n,p)^{24}Na$	3.091E+01	0.0277	1.17	0.0760	
$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$	l		58Ni(n,p)58Co	7.235E+00	0.0209	1.14	0.0667	
$\begin{array}{c cccc} & & & & & & & & & & & & & & & & & $	ľ		⁵⁹ Co(n, γ) ⁶⁰ Co	3.026E+01	0.0376	1.24	0.0828	1
$\begin{array}{c} \begin{array}{c} \begin{array}{c} \begin{array}{c} 115 \text{In}(n,\gamma)^{116}\text{In} & 3.653\text{E}+06 & 0.0341 & 1.26 & 0.0852 \\ \text{scattering box 1} & 56\text{Fe}(n,p)^{56}\text{Mn} + \\ \begin{array}{c} 56\text{Fe}(n,p)^{56}\text{Mn} + \\ 55\text{Mn}(n,\gamma)^{56}\text{Mn} + \\ \begin{array}{c} 1.151\text{E}+03 & 0.0470 & 1.31 & 0.0820 \\ \end{array} & \begin{array}{c} 0.0470 & 1.31 & 0.0820 \\ \end{array} & \begin{array}{c} 0.0358 & 1.06 & 0.1113 \\ \end{array} & \begin{array}{c} 0.0470 & 1.31 & 0.0820 \\ \end{array} & \begin{array}{c} 0.0358 & 1.06 & 0.1113 \\ \end{array} & \begin{array}{c} 0.0470 & 1.31 & 0.0820 \\ \end{array} & \begin{array}{c} 0.0358 & 1.06 & 0.1113 \\ \end{array} & \begin{array}{c} 0.0470 & 1.31 & 0.0820 \\ \end{array} & \begin{array}{c} 0.0358 & 1.06 & 0.1133 \\ \end{array} & \begin{array}{c} 0.0470 & 1.31 & 0.0820 \\ \end{array} & \begin{array}{c} 0.0152 & 1.26 & 0.1323 \\ \end{array} & \begin{array}{c} 0.0152 & 1.26 & 0.1323 \\ \end{array} & \begin{array}{c} 0.0749 & 0.0161 & 1.25 & 0.0749 \\ \end{array} & \begin{array}{c} 0.0717 & 0.0717 \\ \end{array} & \begin{array}{c} 0.058 & 0.0318 & 1.12 & 0.0170 \\ \end{array} & \begin{array}{c} 0.0318 & 1.12 & 0.0170 \\ \end{array} & \begin{array}{c} 0.00774 & 0.0287 & 1.20 & 0.0774 \\ \end{array} & \begin{array}{c} 0.0774 & 0.0309 & 1.24 & 0.0753 \\ \end{array} & \begin{array}{c} 0.0301 & 1.01 & 0.0776 \\ \end{array} & \begin{array}{c} 0.0301 & 1.01 & 0.0776 \\ \end{array} & \begin{array}{c} 0.0357 & 1.25 & 0.0779 \\ \end{array} & \begin{array}{c} 0.0357 & 1.25 & 0.0779 \\ \end{array} & \begin{array}{c} 0.00776 & 0.0357 & 1.25 & 0.0779 \\ \end{array} & \begin{array}{c} 0.00776 & 0.0357 & 1.25 & 0.0779 \\ \end{array} & \begin{array}{c} 0.00776 & 0.0357 & 1.25 & 0.0779 \\ \end{array} & \begin{array}{c} 0.00776 & 0.0357 & 1.25 & 0.0779 \\ \end{array} & \begin{array}{c} 0.00776 & 0.00357 & 1.25 & 0.0779 \\ \end{array} & \begin{array}{c} 0.00776 & 0.00357 & 1.25 & 0.0779 \\ \end{array} & \begin{array}{c} 0.00776 & 0.0426 & 0.98 & 0.0839 \end{array} & \begin{array}{c} 0.00426 & 0.98 & 0.0839 \end{array} $ & \begin{array}{c} 0.00426 & 0.98 & 0.0839 \end{array} & \begin{array}{c} 0.00426 & 0.98 & 0.0839 \end{array}			$^{197}Au(n,\gamma)^{198}Au$	2.987E+04	0.0314	1.24	0.0776	
$\begin{array}{c} \text{Case 4} & \overset{115}{5} \text{In}(n,n^{*}\gamma)^{115\text{m}} \text{In} & 3.429 \text{E}+02 & 0.0368 & 1.06 & 0.1113 \\ \text{scattering box 1} & \overset{56}{5} \text{Fe}(n,p)^{56} \text{Mn} + \\ & \overset{55}{5} \text{Mn}(n,\gamma)^{56} \text{Mn} + \\ & \overset{1.15}{5} \text{IE}+03 & 0.0470 & 1.31 & 0.0820 \\ & \overset{24}{4} \text{Mg}(n,p)^{24} \text{Na} & 1.451 \text{E}+00 & 0.0143 & 1.20 & 0.1358 \\ & \overset{58}{5} \text{Ni}(n,p)^{58} \text{Co} & 4.076 \text{E}-01 & 0.0152 & 1.26 & 0.1323 \\ \hline \text{Case 5} & \overset{59}{5} \text{Co}(n,\gamma)^{60} \text{Co} & 3.521 \text{E}+01 & 0.0161 & 1.25 & 0.0749 \\ & \overset{197}{7} \text{Au}(n,\gamma)^{198} \text{Au} & 3.285 \text{E}+04 & 0.0163 & 1.27 & 0.0717 \\ \hline \text{Scattering box 2} & \overset{59}{5} \text{Co}(n,\gamma)^{60} \text{Co} & 5.479 \text{E}+01 & 0.0287 & 1.20 & 0.0774 \\ & \overset{59}{5} \text{Ni}(n,p)^{58} \text{Co} & 1.767 \text{E}+00 & 0.0301 & 1.01 & 0.0776 \\ \hline \text{Case 6} & \overset{59}{5} \text{Co}(n,\gamma)^{60} \text{Co} & 4.946 \text{E}+01 & 0.0270 & 1.20 & 0.0776 \\ \hline \text{Case 7} & \overset{59}{5} \text{Co}(n,\gamma)^{60} \text{Co} & 4.946 \text{E}+01 & 0.0277 & 1.25 & 0.0779 \\ & \text{scattering box 4} & \overset{59}{5} \text{Ni}(n,p)^{58} \text{Co} & 1.787 \text{E}+00 & 0.0426 & 0.98 & 0.0839 \\ \hline \end{array}$			$^{115}In(n,\gamma)^{116}In$	3.653E+06	0.0341	1.26	0.0852	
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$		Case 4	$^{115}In(n,n'\gamma)^{115m}In$	3.429E+02	0.0368	1.06	0.1113	
$\begin{array}{ c c c c c c c c c c c c c c c c c c c$		scattering box 1	56 Fe(n,p) 56 Mn + 55 Mn(n, γ) 56 Mn	1.151E+03	0.0470	1.31	0.0820	
$\begin{array}{ c c c c c c c c c c c c c c c c c c c$			²⁴ Mg(n,p) ²⁴ Na	1.451E+00	0.0143	1.20	0.1358	
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$			⁵⁸ Ni(n,p) ⁵⁸ Co	4.076E-01	0.0152	1.26	0.1323	
$ \begin{array}{c} \text{Case 5} \\ \text{scattering box 2} \end{array} \stackrel{197}{\sim} \text{Au}(n,\gamma)^{198} \text{Au} & 3.285 \text{E}+04 & 0.0163 & 1.27 & 0.0717 \\ \hline \text{scattering box 2} \end{array} \stackrel{197}{\sim} \text{Au}(n,\gamma)^{198} \text{Au} & 3.285 \text{E}+04 & 0.0163 & 1.27 & 0.0717 \\ \hline \text{scattering box 3} \end{array} \stackrel{59}{\sim} \text{Co}(n,\gamma)^{60} \text{Co} & 2.128 \text{E}-01 & 0.0318 & 1.12 & 0.1170 \\ \hline \begin{array}{c} \text{Case 6} \\ \text{scattering box 3} \end{array} \stackrel{59}{\sim} \text{Co}(n,\gamma)^{60} \text{Co} & 5.479 \text{E}+01 & 0.0287 & 1.20 & 0.0774 \\ \hline \begin{array}{c} \text{scattering box 3} \end{array} \stackrel{197}{\sim} \text{Au}(n,\gamma)^{198} \text{Au} & 5.436 \text{E}+04 & 0.0309 & 1.24 & 0.0753 \\ \hline \begin{array}{c} \text{scattering box 3} \end{array} \stackrel{59}{\sim} \text{Co}(n,\gamma)^{60} \text{Co} & 4.946 \text{E}+01 & 0.0270 & 1.20 & 0.0776 \\ \hline \begin{array}{c} \text{case 7} \\ \text{scattering box 4} \end{array} \stackrel{59}{\sim} \text{Co}(n,\gamma)^{198} \text{Au} & 4.889 \text{E}+04 & 0.0357 & 1.25 & 0.0779 \\ \hline \begin{array}{c} \text{scattering box 4} \end{array} \stackrel{58}{\sim} \text{Ni}(n,p)^{58} \text{Co} & 1.787 \text{E}+00 & 0.0426 & 0.98 & 0.0839 \end{array} $		Cose 5	⁵⁹ Co(n, γ) ⁶⁰ Co	3.521E+01	0.0161	1.25	0.0749]
$ \begin{array}{c ccccccccccccccccccccccccccccccccccc$		Case 5	$^{197}Au(n,\gamma)^{198}Au$	3.285E+04	0.0163	1.27	0.0717	
$\begin{array}{c ccccccccccccccccccccccccccccccccccc$		scattering box 2	58Ni(n,p)58Co	2.128E-01	0.0318	1.12	0.1170	
$ \begin{array}{c} \text{Case 0} \\ \text{scattering box 3} \end{array} \stackrel{197}{\xrightarrow{59}{}} \text{Au}(n,\gamma)^{198} \text{Au} \\ \frac{58}{8} \text{Ni}(n,p)^{58} \text{Co} \\ \text{Case 7} \\ \text{scattering box 4} \end{array} \stackrel{59}{\xrightarrow{59}{}} \text{Co}(n,\gamma)^{60} \text{Co} \\ \frac{59}{107} \text{Au}(n,\gamma)^{198} \text{Au} \\ \frac{4.889 \text{E}+04}{588} \text{Ni}(n,p)^{58} \text{Co} \\ \frac{197}{1.787 \text{E}+00} \\ \frac{59}{1.787 \text{E}+00} \\ \frac{59}{1.25} \\ \frac{59}{$		Coso 6	⁵⁹ Co(n, γ) ⁶⁰ Co	5.479E+01	0.0287	1.20	0.0774]
$ \begin{array}{ c c c c c c c c c c c c c c c c c c c$		Case o	$^{197}Au(n,\gamma)^{198}Au$	5.436E+04	0.0309	1.24	0.0753	
$ \begin{array}{c} Case \ 7 \\ scattering \ box \ 4 \end{array} \begin{array}{c} {}^{59}Co(n,\gamma)^{60}Co & 4.946E+01 & 0.0270 & 1.20 & 0.0776 \\ {}^{197}Au(n,\gamma)^{198}Au & 4.889E+04 & 0.0357 & 1.25 & 0.0779 \\ {}^{58}Ni(n,p)^{58}Co & 1.787E+00 & 0.0426 & 0.98 & 0.0839 \end{array}$		scattering box 3	58Ni(n,p)58Co	1.767E+00	0.0301	1.01	0.0776	
$\begin{array}{c} \text{Case } 7 \\ \text{scattering box 4} \end{array} \begin{array}{c} {}^{197}\text{Au}(n,\gamma)^{198}\text{Au} & 4.889\text{E}{+}04 & 0.0357 & 1.25 & 0.0779 \\ {}^{58}\text{Ni}(n,p)^{58}\text{Co} & 1.787\text{E}{+}00 & 0.0426 & 0.98 & 0.0839 \end{array}$		Casa 7	⁵⁹ Co(n,γ) ⁶⁰ Co	4.946E+01	0.0270	1.20	0.0776	
⁵⁸ Ni(n,p) ⁵⁸ Co 1.787E+00 0.0426 0.98 0.0839		Case /	$^{197}Au(n,\gamma)^{198}Au$	4.889E+04	0.0357	1.25	0.0779	
		scattering box 4	58Ni(n,p)58Co	1.787E+00	0.0426	0.98	0.0839	



New: FUND-NCERC-PU-HE3-MULT-002

- NCERC W-Reflected Pu Sphere
 - Benoit Richard
 - Jesson Hutchenson



Subcritical measurements with varying reflector thickness

Case	Tungsten Thickness (in.)	R ₁ (cts/s)	σ	(C-E)/E (%)	R ₂ (cts/s)	σ	(C-E)/E (%)	M_L	σ	(C-E)/E (%)
1	0.0	9387.38	3.14	4.06	1752.88	9.65	6.64	3.545	0.023	5.16
2	0.5	13402.94	4.10	1.83	4810.58	17.46	0.38	4.473	0.022	-0.71
3	1.0	17273.83	5.12	0.84	10174.02	29.20	-2.40	5.514	0.024	-4.43
4	1.5	21518.23	6.36	0.04	19521.57	49.74	-3.38	6.644	0.026	-5.66
5	2.0	26082.81	7.81	-0.15	34258.82	79.50	-4.05	7.865	0.029	-6.28
6	2.5	30718.62	9.44	-0.46	55664.39	122.18	-4.33	9.137	0.029	-7.08
7	2.75	32958.73	10.29	-0.57	68657.54	146.86	-4.49	9.834	0.035	-6.20
8	3.0	35236.45	11.16	-1.00	83636.32	175.06	-5.42	10.442	0.032	-7.29



Evaluations Planned for Future ICSBEP Publication

- Bettis TRX Critical Experiments
- INL/NASA UF6 Spherical Gas-Core Reactor
- IRSN/Valduc H2O-Moderated LEUO2 Rods with CH2 Core
- IPEN/MB-01 Subcritical Experiments
- NCERC Cu-Reflected Pu Sphere

- SNL Ti Experiments in BUCCX
- JAEA TRACY Critical and Supercritical Experiments
- Westinghouse Saxton Plutonium Project
- Transient Reactor Test (TREAT)
- > GODIVA-IV Revision



International Handbook of Evaluated Reactor Physics Benchmark Experiments

September 2016 Edition

- 21 Contributing Countries
- > 50 Reactor Facilities
- Data from 151 Experimental Series
 - 147 Approved Benchmarks
 - 4 DRAFT Benchmarks







http://irphep.inl.gov/

http://www.oecd-nea.org/science/wprs/irphe/



Breakdown of Current Reactor Facilities on IRPhEP Handbook

- 6 Pressurized Water Reactor (PWR) \geq
 - ✤ DIMPLE, DUKE, EOLE, OTTOHAHN, SSCR, VENUS
- 3 Vodo-Vodynaoi Energetichesky **Reactor (VVER)**
 - ✤ LR-0, P-Facility, ZR-6
- O Boiling Water Reactor (BWR)
- 9 Liquid Metal Fast Reactor (LMFR) \geq
 - ✤ BFS-1, BFS-2, BR2, FFTF, JOYO, SNEAK, ZEBRA, ZPPR, ZPR
- 5 Gas Cooled (Thermal) Reactor (GCR)
 - ✤ ASTRA, HTR10, HTTR, PROTEUS, VHTRC
- 1 Gas Cooled Fast Reactor (GCFR) \geq
 - ✤ PROTEUS

- 5 Light Water Reactor (LWR) \geq
 - ✤ CROCUS, DIMPLE, IPEN(MB01), **KRITZ, TCA**
- **3 Heavy Water Reactor (HWR)**
 - ✤ DCA, ETA, ZED2
- 0 Molten Salt Reactor (MSR)
- **1 Reaktor Bolshoy Moshchnosti** Kanalniy (RBMK)
 - ✤ RBMK(CF)
- 6 Space Reactor (SPACE)
 - ORCEF, SCCA, TOPAZ, UKS1M, **ZPPR, ZPR**
- **19 Fundamental Physics Reactor Measurements (FUND)**
 - ATR, BFS-1, BFS-2, CORAL(1), FR0, HECTOR, IGR, KUCA, LAMPRE, MINERVE, NRAD, ORSPHERE, PBF, RA-6, RB, RHF, TRIGA, ZEBRA, ZPR



Recent Revisions to the Handbook

4 Revisions

***ZPR-FUND-EXP-009**

- o **ZPR-6/10**
- Improved uncertainty analysis

PFacility-VVER-EXP-001

• VVER Lattice

daho National

 Fixed Hf absorber rod diameter error in figure SCCA-SPACE-EXP-003

- Be-Reflected HEUO2
 Space Reactor
 Mockup
- Added evaluation of potassium core

- **ZPPR-2**
- Added evaluation of sodium channeling measurements



Revision: ZPR-FUND-EXP-009

≻ ANL – ZPR-6/10

- Pu/C/SST Assembly Reflected by SS/Fe
 Dials Lall
- Rich Lell
- Updated uncertainty analysis based on results from more recent ZPR/ZPPR benchmark evaluations





Table 4.1. Sample Calculation Results for Case 1, ZPR-6/10 Loading 24.

Code	Cross	Calcu	lation	С/Е -	1
	Sections	k _{eff}	σ	C/E-1, %	σ, %
KENO V.a	238-Group ENDF/B-V	1.0269	0.0009	3.96	0.26
KENO V.a	27-Group ENDF/B-IV	1.0262	0.0009	3.89	0.26
MCNP-4B	Cont. Energy ENDF/B-V	1.0038	0.0010	1.62	0.26
MCNP-4C	Cont. Energy ENDF/B-V	0.9945	0.0005	0.68	0.24
MCNP-4C	Cont- Energy ENDF/B-VI	1.0245	0.0005	3.72	0.25
VIM	Cont. Energy ENDF/B-V	0.9862	0.0005	-0.16	0.24
VIM	Cont. Energy ENDF/B-VI	1.0222	0.0006	3.48	0.25
MONK-8B ^(a)	8220-Group UKNDL	1.0444	0.0009	5.73	0.26
MONK-8B ^(a)	13193-Group JEF-2.2	1.0115	0.0009	2.40	0.26
MONK-8B ^(a)	13193-Group ENDF/B-VI	1.0324	0.0009	4.52	0.26
MCNP6	Cont. Energy ENDF/B-VII.1	1.0148	0.0001	2.73	0.24

(a) Results supplied by M. A. Smith (ANL)

Revision: PFacility-VVER-EXP-001

> Kurchatov

- VVER Physics Experiments
- ♦ P-Facility
- Corrected error in benchmark diagram for absorber rod diameter
 - Figure 8





Revision: SCCA-SPACE-EXP-003

- Be-Reflected HEUO2 Space Reactor Mockup
 - *ORCEF
 - Margaret Marshall (INL)
- Added two configurations with a steel calandria and then potassium to simulate coolant



SCCA-SPACE-EXP-003 Results

Calculation of potassium worth significantly poor.
Recommend identification and evaluation of additional potassium measurements before refining nuclear data.

		Potassium Worth		(C-E)/E ^(a)		(C-E) ^(a) (Δ¢)				
Benchmark Worth		18.6	±	6.72	. 					
MCNP5	ENDF-B-VII.0	-3.42	±	0.259	-118	±	6.80 %	-22.02	±	6.73
MCNP5	ENDF-B-VII.1	0.41	±	0.195	-98	±	1.32 %	-18.19	±	6.72
MCNP5	JEFF-3.1	-4.25	±	0.287	-123	±	8.39 %	-22.85	±	6.73
MCNP5	JENDL-3	-19.32	±	0.985	-204	±	37.90 %	-37.92	±	6.79
KENO	ENDF-B-VII.0	1.30	±	1.581	-93	±	8.87 %	-17.30	±	6.91

Table 4.4-5. Calculation Results for Potassium Worth.

(a) "E" is the experimental benchmark value. "C" is the calculated value.



Revision: ZPPR-LMFR-EXP-011

> ANL – ZPPR-2

- MOX w/ Na Reflected by DU, Na, SS
- Rich Lell
- Added neutron spectra and sodium void worth measurements in a plate-loaded core
 - Small worths with relatively large experimental uncertainties contribute to large calculation deviations.





Draft Additions to the Handbook

2 New Drafts

* DIMPLE

- UK Winfrith Reactor
- CERES Phase II program to validate fission product poisoning

♦ VENUS-17

- o Mol, Belgium
- Varying MOX loading experiments

- Draft evaluations aren't approved benchmarks
- Provide avenue for data preservation
 - Make available for public use until evaluation can be completed





New Draft: DIMPLE-LWR-EXP-003

LWR UO2 Lattice Core

David Hanlon (UK)

- Part of UK/CEA CERES collaboration
- Phase II: Reactivity measurements of fission product simulant samples
 - ✤ Sm, Nd, Gd, Eu, Rh, Ag, Cs, Ru, Mo





New Draft: VENUS-PWR-EXP-006

VENUS-17 Plutonium Recycle Physics Project (Belgium)

Kevin Hesketh (UK)

Study of different MOX fuel with varying Pu content and isotopics



Recent Additions to the Handbook

2 Completed Drafts *****DUKE Depletion Reactivity **♦** MINERVE • CERES ≻6 New ♦ IPEN/MB-01 Isothermal Reactivity Coefficient • Mo Rods V ARRIVA aho National La

⇔ LR-0

- VVER-1000
 Experiments with
 Graphite and Fluoride
 Salt Insertions
- * PROTEUS
 - o GCFR Core 11
- Reactor B
 - Internal Neutron Converters
- * TRIGA
 - Reaction Rate Distribution Measurements

New: DUKE-PWR-POWER-001

- PWR Depletion Reactivity Measurements
 - ***Kord Smith (MIT)**
 - Dale Lancaster

Missed 2016 publication deadline *Will be in 2017

edition

Use of inferred reactivities to determine mean reactivity change due to burnup

Burnup GWd/T	Calculated k _{inf}	Monte Carlo σ	Calculated Reactivity	Experimental Benchmark Reactivity	Depletion Reactivity Bias C–E	Depletion Reactivity (C-E)/E (%)
0	1.1045	0.0001				
10	1.1127	0.0001	0.0082	0.0096	-0.0014	-14.6
20	1.0611	0.0001	-0.0434	-0.0421	-0.0013	3.1
30	0.9944	0.0001	-0.1101	-0.1082	-0.0019	1.8
40	0.9327	0.0001	-0.1718	-0.1711	-0.0007	0.4
50	0.8772	0.0001	-0.2273	-0.2265	-0.0008	0.4
60	0.8316	0.0001	-0.2729	-0.2729	0.0000	0.0



New: MINERVE-FUND-RESR-001

- French MINERVE Reactor
 - Alain Santamarina
- CERES II fission product worth measurements
 - Sm, Nd, Gd, Eu, Rh, Cs, Mo, Tc
 - Calculation agreement within 5% except for Cs, Tc (10%)





New: IPEN(MB-01)-LWR-RESR-017

Brazil – UO2 LWR **Core Loadings** Temperature (°C) 0 10 20 30 66.6 * Adimir $T_{inv}(^{\circ}C)=20.61 \pm 0.10$ Experimental JEFF (CIELO dos Santos ENDF/B-VII.0 - 0 Positior Inversion point 66.4 T_{inv}(°C)=18.06 ± 0.10 of the isothermal **3C2 Control Bank Critical** (% withdrawn) -20 reactivity 66.2 coefficient T_{inv}(°C)=22.36±0.26 for three -40 configurations 66.0 Calculations -60

0

10

20

Temperature (°C)

30

slightly off by a few degrees

(relative to the 20 °C case)

Reactivity (pcm)

New: IPEN(MB-01) -LWR-RESR-018

- Brazil UO2 LWR Core with Mo Rods *Adimir dos Santos
- Investigated solid Mo rods in thermal spectra
 - Excellent calculation agreement



Code (Cross	MCNP5	Benchmark Value	(C-E)/E %
Section Set) →	(Continuous Energy	$k_{eff} \pm \sigma$	
Case Number ↓	ENDF/B-VII.0)		
1	1.00086 ± 0.00004	1.0005 ± 0.0005	0.036 ± 0.048
2	1.00068 ± 0.00004	1.0004 ± 0.0005	0.028 ± 0.048
3	1.00082 ± 0.00004	1.0004 ± 0.0005	0.042 ± 0.048
4	1.00094 ± 0.00004	1.0005 ± 0.0005	0.044 ± 0.048

New: LR(0)-VVER-RESR-003

- VVER-1000 Physics Experiments
 - Research Center Rez
- Investigate reactor physics problems for MSR and FHR *FLINA and FLIBE *Criticality only

aho National Laboratory



17 Loadings Calculations within 20 of benchmark values.

41

New: PROTEUS-GCFR-RESR-001

- (PSI) GCFR-PROTEUS Core 11
 - Gareth Newman (UF)
- Coupled fastthermal reactor spectral measurements
 - Generally good agreement except a few outliers





New: RB-FUND-EXP-008

Serbia RB Reactor

Milan Pesic

> U-metal and/or UO2 fueled HWR

Three core loadings to develop Internal Neutron Converter (INC)

Code (Cross Section Set) → Core No./Year ↓:	Experimental k_{eff} + bias (E)	Benchmark k _{eff}	MCNP6.1.1b (Continuous-energy ENDF/B-VII.1), ^(a) (C) ^(b)	(C-E)/E (%)
RB59/1983 (INC-0)	1.00083 ± 0.00015	1.00083 ± 0.00132	1.00071 ± 0.00003	-0.011 ± 0.015
RB60/1984 (INC-2)			1.00132 ± 0.00003	0.049 ± 0.015
RB61/1984 (INC-1)			1.00150 ± 0.00003	0.067 ± 0.015



Horizontal cross section at elevation of 50 cm





(a) ENDF/B-VII.1 library for all nuclides, TSL from ENDF71SAB at 293.6 K.

(b) Results supplied by J. D. Bess (INL) obtained with MCNP6.1.1b with 500 million neutron histories.



New: TRIGA -FUND-RESR-002

Slovenia

- ✤ Ziga Stancar✤ Luke Snoj
- Absolute fission rate distribution measurements to support thermal power calibration
 - Numerous measurements throughout core



Evaluations Planned for Future IRPhEP Publication

- > AGN-201M @ ISU
- IPEN/MB-01 Subcritical Measurements
- BWR Cold Critical Experiments
- KRITZ-1 Experiment
- EBR-II Loading 138
- > ORNL MSRE
- BEAVERS Benchmark

- LR-0 VVER-1000 Measurements
- Additional measurements in KUCA and HTR-PROTEUS
- GCFR-PROTEUS additional cores
- Transient Reactor Test (TREAT) Facility



International Collaboration on Minor Actinide Irradiation Measurements

- Validation of Minor Actinide Cross Sections
 - **ORNL-JAEA** Project
 - Irradiated in Dounreay Prototype Fast Reactor
 - Joint collaboration between IRPhEP and SFCOMPO
 - Need Dounreay PFR data to perform quality benchmark evaluation



Conclusions

- The ICSBEP and IRPhEP continue to provide high-quality integral benchmark data
- Valuable for nuclear data testing, uncertainty reduction, criticality safety, reactor physics, advanced modeling and simulation
- Data contributed from 25 countries
- Enable current and future activities supported by experimental validation



Questions?





📉 Idaho National Laborator

Extra Slides





Countries Participating in the ICSBEP & IRPhEP

- Argentina
- > Belgium
- Brazil
- Canada
- People's Republic of China
- Czech Republic
- France
- Germany
- Hungary
- India
- Israel
- > Italy
- Japan

- Kazakhstan
- Poland
- Republic of Korea
- Russian Federation
- Serbia
- Slovenia
- South Africa
- Spain
- Sweden
- Switzerland
- United Kingdom
- United States of America

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Denmark	Israel	Portugal	United Kingdom
Estonia	Italy	Republic of Korea	United States
Finland	Japan	Russian Federation	





