

Input Information for SG46 Target Accuracy Requirements (TAR) Exercise using Models of 750MWe JSFR Core

Kenji Yokoyama

Research Group for Reactor Physics and

Standard Nuclear Code System

Japan Atomic Energy Agency (JAEA)



Action Agreed at June 2019 Meeting*

- **For those providing models**, it is requested that they provide a list of recommended integral parameters, associated sensitivities, and uncertainty analyses. Based on uncertainty analysis a recommended list of isotopes for TAR will be provided **by the next meeting**.
- Note that the format for sensitivity should be those recommended by SG33. Uncertainty tables should also follow recommendations made in SG33.
- Note that the list of reaction for sensitivity is: capture (includes: (n,γ) , (n,α) , (n,p) , etc.), fission, ν , χ , elastic, inelastic, μ .



Results of sensitivity and uncertainty analyses using 750MWe JSFR model** are to be reported

*: Summary Record, Meeting of WPEC SG46, 25-26 June 2019, NEA/NSC/WPEC/DOC(2019)4

** : K. Sugino et al., Models of the 750MWe JSFR core, SG46 meeting, 27 November 2018

Tools and Data for Analyses

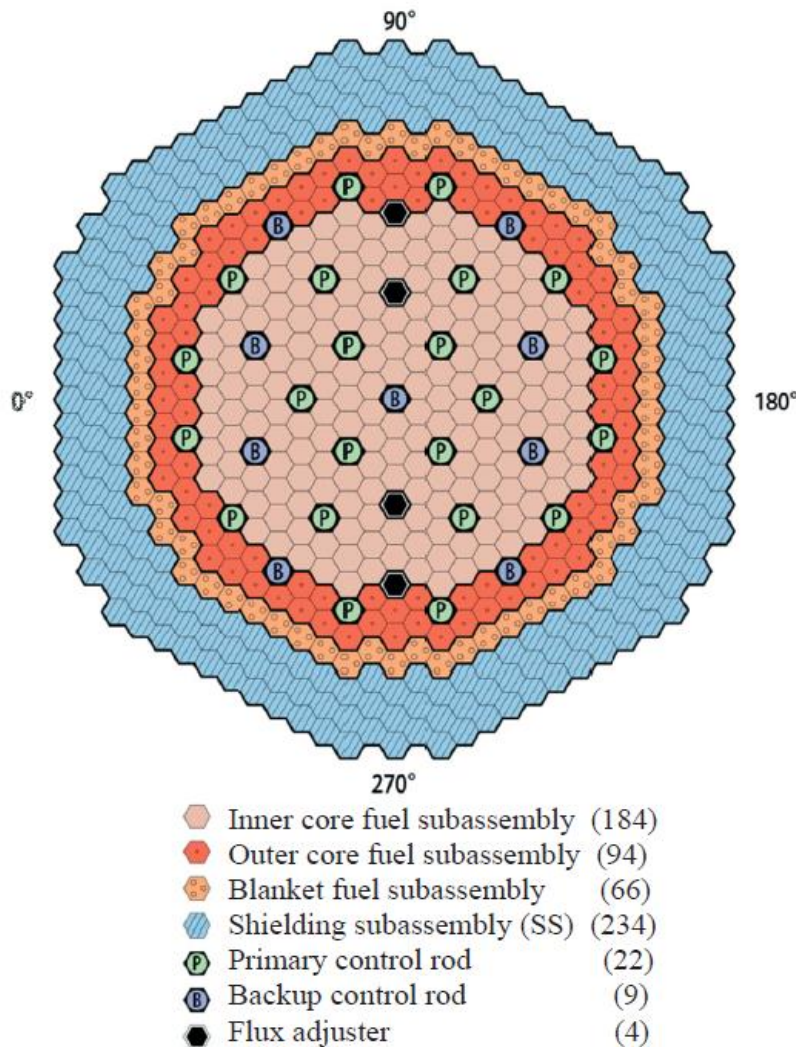
- Sensitivity coefficients:
 - MARBLE/SAGEP code system based on GPT (generalized perturbation theory) [1-3] for static integral parameters
 - MARBLE/PSAGEP code system based on DPT (depletion perturbation theory) [4-6] for time-dependent integral parameters
- Covariance of nuclear data:
 - JENDL-4.0 [7]
 - Processed by NJOY99.396
- Energy group structure:
 - Equivalent to the 7-group structure proposed in SG46*

- [1] L. N. Usachev, J. Nucl. Energy A/B 18, 571-583 (1964)
[2] A. Gandini, J. Nucl. Energy 21, 755-765 (1967)
[3] W. M. Stacey Jr., J. Math. Phys. 13, 1119-1125 (1972)
[4] A. Gandini, et al., NSE 62, 339-345 (1977)
[5] M. L. Williams, NSE 70, 20-36 (1979)
[6] T. Takeda, et al., NSE 91, 1-10 (1985)
[7] K. Shibata, et al., J. Nucl. Sci. Technol. 48[1], 1-30 (2011)

Table 7-energy group structure

Group	SG46 proposed (eV)*	This analysis (eV)
1	1.9640E+07	2.0000E+07
2	2.2313E+06	←
3	4.9787E+05	←
4	6.7378E+04	←
5	2.0347E+03	←
6	2.2603E+01	←
7	5.4000E-01	5.3158E-01

Review of 750MWe JSFR Model



- A document[1] on 2-D RZ models of 750MWe JSFR[2], which is designed as a demonstration phase fast reactor in Japan, were provided for SG46 TAR exercise
- In the document, two models are included:
 - Simplified model (fresh fuel = BOL) by Table A.2 and Fig. A.2
 - Detailed model (EOEC) by Table A.2 and Fig. A.2

[1] K. Sugino, et al., Models of the 750MWe JSFR core, SG46 meeting, 27 November 2018

[2] T. Kan, et al, Proc. Int. Conf. of ICAPP2017, April 24-28, 2017, Fukui and Kyoto, Japan

List of Recommended Integral Parameters

The following integral parameters are considered in the sensitivity and uncertainty analyses:

- ① Criticality (Multiplication factor) = K_{EFF}
(BOL: simplified model)
- ② Power distribution = $F_{49}(OCE/CC)^*$
(BOL: simplified model)
- ③ Single control rod worth** = CRW
(BOL: simplified model)
- ④ Sodium void reactivity = SVR
(EOEC: detailed model)
- ⑤ Doppler reactivity = DOP
(BOL: simplified model)
- ⑥ Burnup reactivity swing = BRS
(in the 6th cycle started with the simplified model (BOL))

* $F_{49}(OCE/CC)$: Pu-239 fission rate ratio between the outer core edge and the core center

** BCR (backup control rod) in the core center

Examples of Sensitivity Coefficients

Fig. JSFRtable1 KEFF Pu-239

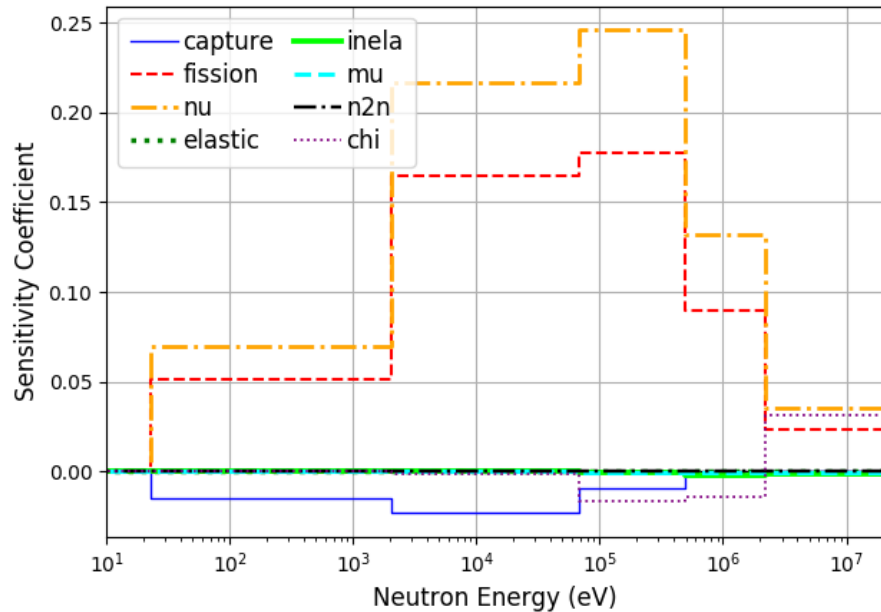


Fig. Sensitivity coefficients of criticality with respect to Pu-239

Fig. JSFRtable2 SVR Na-23

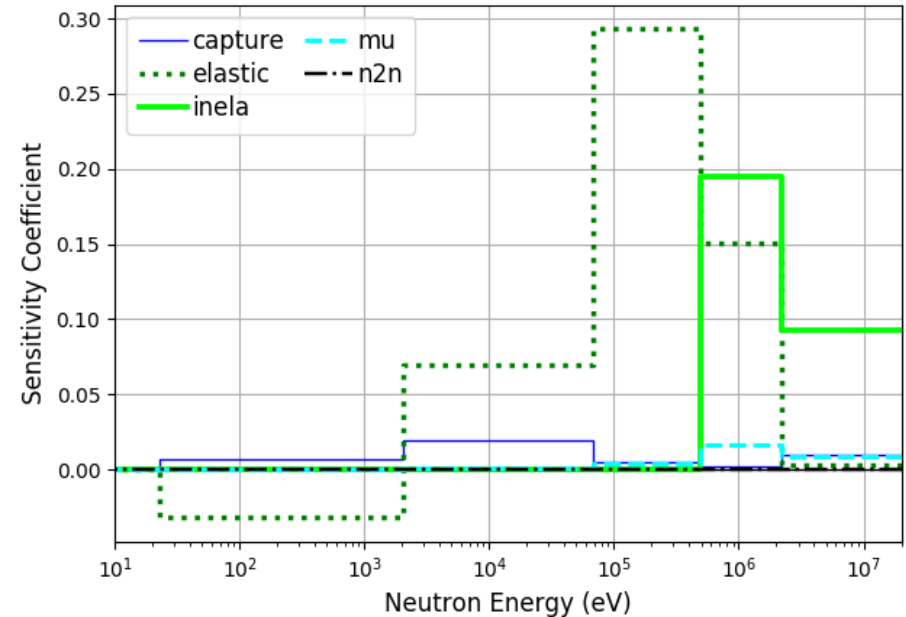


Fig. Sensitivity coefficients of sodium void reactivity with respect to Na-23

- Sensitivity coefficients for JSFR show typical trends of those for a sodium-cooled fast reactor

*: capture includes (n, γ), (n,p), (n, α), ... (ENDF/MT: 102 – 117)

Covariance Used in Uncertainty Analysis

- The following covariance data of JENDL-4.0 are used in the uncertainty analysis
 - capture*, fission, ν , elastic, inelastic, μ , (n,2n), χ
 - U-234, U-235, U-236, U-238,
 - Np-237, Np-239
 - Pu-238, Pu-239, Pu-240, Pu-241, Pu-242
 - Am-241, Am-242m, Am-243
 - Cm-242, Cm-243, Cm-244, Cm-245, Cm-246
 - capture, elastic, inelastic, μ , (n,2n)
 - O-16, Na-23, Cr-52, Cr-53, Fe-56, Ni-58, Ni-60
 - capture, elastic, inelastic, (n,2n)
 - Mn-55
 - capture, elastic
 - B-10, B-11
- The following covariance data are not included in JENDL-4.0 and ignored in the uncertainty analysis
 - C-12, Cr-50, 54, Fe-54, 57, 58, Ni-61, 62, 64, Mo-92, 94-98, 100, W-180, 182-184, 186, Nd-143

*: (n, α) is used for B-10 and (n, γ) is used for the others

Results of Uncertainty Analysis

Parameter	This Analysis	Parameter*	Preliminary Revised Design Target Accuracy*
Criticality (BOL)	0.756% (= 756pcm)	Multiplication factor (BOL)	200pcm
Power distribution (F49) (BOL)	1.26%	Power peak (BOL)	1%
Single control rod worth in the core center (BOL)	2.33%	Single control rod	2%
Sodium void reactivity (EOEC)	4.84%	Reactivity coefficient (Coolant void and Doppler – BOL/EOL)	3%
Doppler reactivity (BOL)	3.08%		
Burnup reactivity swing (= 1.1%dk/kk' nominal)	6.16% (= 68pcm)	Burnup reactivity swing	200pcm

*: M. Salvatores, Introduction to TAR, SG46 meeting, 25-26 June 2019

Important Nuclides for Uncertainty Analysis (1/2)

Table Nuclide-wise uncertainties for integral parameters of JSFR in descending order

KEFF	Unc.(%)	F49	Unc.(%)	CRW	Unc.(%)	SVR	Unc.(%)	DOP	Unc.(%)	BRS	Unc.(%)
U-238	0.478	U-238	0.99	U-238	1.45	Na-23	4.54	Na-23	1.78	U-238	5.21
Pu-239	0.437	Fe-56	0.64	Fe-56	1.30	U-238	1.40	Fe-56	1.34	Pu-239	2.76
Fe-56	0.248	Na-23	0.32	Na-23	0.90	Pu-239	1.10	Pu-239	1.28	Pu-240	1.41
Pu-240	0.160	O-16	0.32	O-16	0.58	Fe-56	0.87	U-238	1.20	Pu-241	0.68
Na-23	0.133	Pu-239	0.29	Pu-239	0.56	Pu-241	0.61	O-16	0.69	Am-241	0.54
Pu-241	0.086	Pu-240	0.09	B-10	0.29	Pu-240	0.54	Pu-240	0.60	Cm-244	0.33
O-16	0.075	Pu-241	0.08	Pu-240	0.24	O-16	0.29	Am-241	0.48	Fe-56	0.33
Pu-238	0.066	Cr-52	0.08	Cr-52	0.15	Am-241	0.24	Pu-238	0.31	Na-23	0.29
Am-241	0.059	Am-241	0.04	Pu-241	0.11	Pu-238	0.19	Pu-241	0.28	Am-242m	0.20
Pu-242	0.031	Pu-238	0.03	Pu-238	0.08	Mn-55	0.08	Mn-55	0.14	Am-243	0.19
Am-243	0.029	Mn-55	0.03	Am-241	0.07	Pu-242	0.07	Am-243	0.13	Cm-245	0.17
Cm-245	0.021	Cr-53	0.02	Cr-53	0.06	Am-243	0.06	Cr-53	0.12	Pu-238	0.16
Cm-244	0.020	Pu-242	0.02	Mn-55	0.04	Cm-244	0.06	Pu-242	0.11	O-16	0.14
Cr-52	0.011	Cm-244	0.01	Pu-242	0.04	Cm-245	0.06	Cm-244	0.09	Np-239	0.10
U-235	0.011	Cm-245	0.01	Cm-244	0.04	Cr-52	0.05	Cm-245	0.06	Pu-242	0.08
Mn-55	0.008	U-235	0.01	U-235	0.02	U-235	0.04	Cr-52	0.06	U-235	0.06
Am-242m	0.008	Am-243	0.01	Am-243	0.02	Am-242m	0.04	U-235	0.05	Mn-55	0.05
Cr-53	0.005	Am-242m	0.00	B-11	0.02	Cr-53	0.02	Am-242m	0.03	Cm-242	0.04
Np-237	0.004	B-10	0.00	Cm-245	0.01	Np-239	0.02	Np-237	0.02	Np-237	0.03
Ni-58	0.004	Ni-58	0.00	Am-242m	0.01	B-10	0.02	Ni-58	0.01	B-10	0.03
B-10	0.003	Np-237	0.00	Ni-58	0.00	Cm-242	0.02	B-10	0.01	Cm-243	0.03
Ni-60	0.000	B-11	0.00	Np-237	0.00	Np-237	0.01	Ni-60	0.00	Cr-53	0.02
B-11	0.000	Ni-60	0.00	Ni-60	0.00	Ni-58	0.01	B-11	0.00	Cr-52	0.01
Cm-243	0.000	Cm-243	0.00	Cm-243	0.00	Cm-243	0.00	Cm-243	0.00	U-234	0.01
Cm-242	0.000	Cm-242	0.00	Cm-242	0.00	U-236	0.00	Cm-242	0.00	U-236	0.01
Cm-246	0.000	Cm-246	0.00	Cm-246	0.00	U-234	0.00	Cm-246	0.00	Cm-246	0.01
U-234	0.000	U-234	0.00	U-234	0.00	Cm-246	0.00	U-234	0.00	Ni-58	0.00
U-236	0.000	U-236	0.00	U-236	0.00	B-11	0.00	U-236	0.00	B-11	0.00
Np-239	0.000	Np-239	0.00	Np-239	0.00	Ni-60	0.00	Np-239	0.00	Ni-60	0.00

Important Nuclides for Uncertainty Analysis (2/2)

Table Nuclide-wise cumulative uncertainties for integral parameters of JSFR

	KEFF	cum.*	F49	cum.	CRW	cum.	SVR	cum.	DOP	cum.	BRS	cum.
1	U-238	0.65	U-238	0.76	U-238	0.62	Na-23	0.90	Na-23	0.58	U-238	0.84
2	Pu-239	0.87	Fe-56	0.90	Fe-56	0.83	U-238	0.94	Fe-56	0.73	Pu-239	0.96
3	Fe-56	0.94	Na-23	0.93	Na-23	0.92	Pu-239	0.97	Pu-239	0.84	Pu-240	0.98
4	Pu-240	0.96	O-16	0.97	O-16	0.95	Fe-56	0.98	U-238	0.93	Pu-241	0.99
5	Na-23	0.98	Pu-239	0.99	Pu-239	0.98	Pu-241	0.99	O-16	0.95	Am-241	0.99
6	Pu-241	0.98	Pu-240	0.99	B-10	0.99	Pu-240	1.00	Pu-240	0.97	Cm-244	1.00
7	O-16	0.99	Pu-241	1.00	Pu-240	0.99			Am-241	0.99		
8	Pu-238	0.99			Cr-52	1.00			Pu-238	0.99		
9	Am-241	1.00							Pu-241	1.00		

*: normalized to unity

- Number of important nuclides for uncertainty analysis seems to be limited to about 10

Sensitivity Coefficients in SG33 Format

```

# Date: 14 November 2019
# Lab: JAEA
#
# Data: Sensitivity of I=JSFRtable1 KEFF to p=B-10
#
#          Capt.          Mu-bar          N2n          Elas.          Inel.
# Grp upper E(eV)      MF3/MT102-117 MF3/MT251      MF3/MT16      MF3/MT2      MF3/MT4
#          lowest=1E-5      (no-dim)      (no-dim)      (no-dim)      (no-dim)      (no-dim)
#
#-I2-----E12.4-----E12.4-----E12.4-----E12.4-----E12.4-----E12.4
  1  2.0000E+07      -2.7888E-05 -1.4899E-05   1.4979E-08   3.3924E-05   1.9736E-06
  2  2.2313E+06      -1.9833E-04 -2.7505E-05   0.0000E+00   8.0523E-05  -7.5510E-07
  3  4.9787E+05      -1.1906E-03 -1.9499E-05   0.0000E+00   6.4057E-05   0.0000E+00
  4  6.7380E+04      -8.4892E-04 -5.7656E-06   0.0000E+00   2.9812E-05   0.0000E+00
  5  2.0347E+03       3.6625E-05 -6.3124E-07   0.0000E+00   8.0332E-06   0.0000E+00
  6  2.2603E+01       5.0762E-08 -4.6083E-11   0.0000E+00   5.9956E-10   0.0000E+00
  7  5.3158E-01       2.5946E-10 -3.8993E-14   0.0000E+00   5.0443E-13   0.0000E+00
# Sum over energy -----
                        -2.2291E-03 -6.8299E-05   1.4979E-08   2.1635E-04   1.2185E-06
#
# Data: Sensitivity of I=JSFRtable1 KEFF to p=B-11
#
#          Capt.          Mu-bar          N2n          Elas.          Inel.
# Grp upper E(eV)      MF3/MT102-117 MF3/MT251      MF3/MT16      MF3/MT2      MF3/MT4
#          lowest=1E-5      (no-dim)      (no-dim)      (no-dim)      (no-dim)      (no-dim)
#
#-I2-----E12.4-----E12.4-----E12.4-----E12.4-----E12.4-----E12.4
  1  2.0000E+07      -1.1860E-09 -1.3918E-06   2.3952E-11   4.4483E-06   2.3073E-07
... (continued) ...

```

- Numerical data of the 7-group sensitivity coefficients are stored in the SG33 format for SG46 TAR exercise

Uncertainties in SG33 Format

```

# Date: 14 November 2019
# Lab: JAEA
#
# Data: Uncertainty of I=JSFRtable1 KEFF to p=B-10
#
#           Capt.           Elas.
# Grp upper E(eV)   MF3/MT102-117 MF3/MT2
#   lowest=1E-5     (no-dim)       (no-dim)
#
#-I2-----E12.4-----E12.4-----E12.4
# 1  2.0000E+07      2.3228E-06  9.4674E-07
# 2  2.2313E+06      5.6623E-06  1.2297E-06
# 3  4.9787E+05      1.7587E-05  1.1443E-06
# 4  6.7380E+04      1.1248E-05  5.3185E-07
# 5  2.0347E+03      1.7679E-07  2.3098E-07
# 6  2.2603E+01      2.4442E-10  1.6188E-11
# 7  5.3158E-01      1.2482E-12  1.3620E-14
# Non-diagonal -----
#           2.2082E-05  2.3078E-06
# Sum over energy -----
#           3.0999E-05  3.0627E-06
#
# Data: Uncertainty of I=JSFRtable1 KEFF to p=B-11
#
#           Capt.           Elas.
# Grp upper E(eV)   MF3/MT102-117 MF3/MT2
#   lowest=1E-5     (no-dim)       (no-dim)
#... (continued) ...

```

Only diagonal term is considered as the group-wise uncertainty

Non-diagonal terms of inter-energy are separately evaluated

NB: Non-diagonal terms of inter-nuclide and inter-reaction are not included in the SG33-formatted file

- Results of uncertainty analysis using JENDL-4.0 covariance are also available in the SG33 format

Concluding Remarks

- Results of sensitivity and uncertainty analyses using the 750MWe JSFR model were reported for providing input information of the SG46 TAR exercise
 - 7-group energy structure proposed in SG46
 - Numerical data stored in the SG33 format
- Six integral parameters of JSFR, which relate to the preliminary SG46 revised design target accuracies, are considered in the analyses
 - KEFF, F49(OCE/CC), CRW, SVR, DOP, BRS
- Numerical data of 7-group sensitivity coefficients and group-wise uncertainties are available in the SG33 format