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Used Nuclear Fuel Criticality Safety Benchmark SiO_2 Reflector Effect

The Reflector Effect of Silicon Dioxide (SiO_2) for the Criticality Safety of Direct Disposal of Used Nuclear Fuel

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The mission of the NEA is:

– to assist its member countries in maintaining and further developing, through international co-operation, the scientific, technological and legal bases required for a safe, environmentally sound and economical use of nuclear energy for peaceful purposes;

– to provide authoritative assessments and to forge common understandings on key issues as input to government decisions on nuclear energy policy and to broader OECD analyses in areas such as energy and the sustainable development of low-carbon economies.

Specific areas of competence of the NEA include the safety and regulation of nuclear activities, radioactive waste management and decommissioning, radiological protection, nuclear science, economic and technical analyses of the nuclear fuel cycle, nuclear law and liability, and public information. The NEA Data Bank provides nuclear data and computer program services for participating countries.

Foreword

In 1980, the Nuclear Energy Agency (NEA) initiated a study on the nuclear criticality safety of transport packages designed to contain used light water reactor (LWR) fuel. This included identification of typical challenges. The specification of benchmarks for validation and calculation models for typical package designs resulted in an inter-comparison of calculation methods (transport/diffusion theory, Monte Carlo/deterministic). Specific challenges in that study included treatment of neutron flux traps, homogenisation of materials over various geometry regions and effects of various reflector materials (water, lead and steel). The fuel was modelled as an un-irradiated (fresh) for that initial study. Today, the designs of final disposal canisters for used nuclear fuel have many similarities to transport package designs.

The NEA Expert Group on Burn-up Credit Criticality Safety (EGBUC), with links to the 1980 study mentioned above, has organised several international benchmarks to assess the accuracy and validity of burn-up credit methodologies. They mainly covered storage and transport of used nuclear fuel (UNF). However, many NEA member countries are interested in the direct disposal of UNF, which requires criticality assessment under the condition specialised in the geological disposal cases.

In the criticality safety evaluation for the direct disposal of used nuclear fuel, the geometrical configuration including the used fuel assemblies, primary containment structure (steel), buffer materials (e.g. clay) and the surrounding geology (rock/soil) should be considered. Potential changes in these materials and their geometry over time must also be considered. The container might corrode over the long-term time frame of the geological disposal, causing the container walls to become thinner. The buffer material and the rock/soil surround the used fuel potentially acting as neutron reflectors. The reflector worth of these materials will change as the container changes and could at some point have a larger reactivity effect than the water reflector, which is the usual model in the criticality evaluation.

However, the reflector effect of such materials as clay and rock has not been investigated in detail. To perform the accurate criticality evaluation in the direct disposal of used nuclear fuels, it is necessary to validate the calculation tools and the nuclear data library for the reflector worth of these materials. It is important to ensure that the reflector effect of these materials is consistent for different nuclear data and calculation tools by comparing relevant parameters, such as the neutron multiplication factor or specific reaction rates. In this benchmark, silicon dioxide (SiO_2) is the focus for the inter-comparison since SiO_2 is the major component of clay and soil.

This benchmark consists of two parts, assuming both fresh and used fuel. A simple geometry model representing the reflector effect is assumed for both parts. In the second part, the concept of the burn-up credit is taken into account. The aim of the first part is to compare SiO_2 reflector effect for the simplified condition and the aim of the second part is to compare SiO_2 reflector effect adopting the realistic fuel composition in the direct disposal.

Acknowledgements

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List of participants

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List of abbreviations

A/P	Absorption to production
BfS	Bundesamt für Strahlenschutz (Germany)
CE	Continuous energy
CENDL	Chinese Evaluated Nuclear Data Library
EDF	Électricité de France
EC	European Community
EGBUC	Expert Group on Burn-up Credit Criticality Safety (NEA)
ENDF	Evaluated Nuclear Data File
EMS	E. Mennerdahl Systems
GT	Guide tube
GRS	Global Research for Safety
IRSN	Institut de Radioprotection et de Sûreté Nucléaire
JAEA	Japan Atomic Energy Agency
JEFF	Joint Evaluated Fission and Fusion File (NEA)
JENDL	Japanese Evaluated Nuclear Data Library
L/P	Leakage to production
LWR	Light water reactor
NEA	Nuclear Energy Agency
NCBJ	National Centre for Nuclear Research (Poland)
PWR	Pressurised water reactor
RSD	Relative standard deviation
SD	Standard deviation
TSL	Thermal scattering law
UNF	Used nuclear fuel
WPNCS	Working Party on Nuclear Criticality Safety (NEA)

Executive summary

In the criticality safety evaluation for the direct disposal of used nuclear fuel (UNF), a simple geometrical configuration consisting of fuel assemblies, a steel container, clay buffer material and rock/soil around the container can be used to achieve the calculation objectives. The steel might corrode over the long-term time frame of the geological disposal, causing the steel container walls to become thinner. Thus, the clay buffer material and the rock/soil can act as neutron reflectors surrounding the fuel component. The reflector worth of these materials could potentially have a larger effect on the system reactivity than a water reflector, which is the usual model in the criticality safety evaluation. The aim of this benchmark was to investigate the reflector effect of these materials.

In order to perform accurate criticality evaluations in the direct disposal of UNF, it is necessary to validate the calculation tools and the nuclear data library for the reflector effect of these materials. It is important to ensure that the reflector effect of these materials is consistent for different nuclear data and calculation tools by comparing relevant parameters, such as the neutron multiplication factor or specific reaction rates. In this benchmark, silicon dioxide (SiO_2) is the focus for the inter-comparison since SiO_2 is the major component of clay and soil.

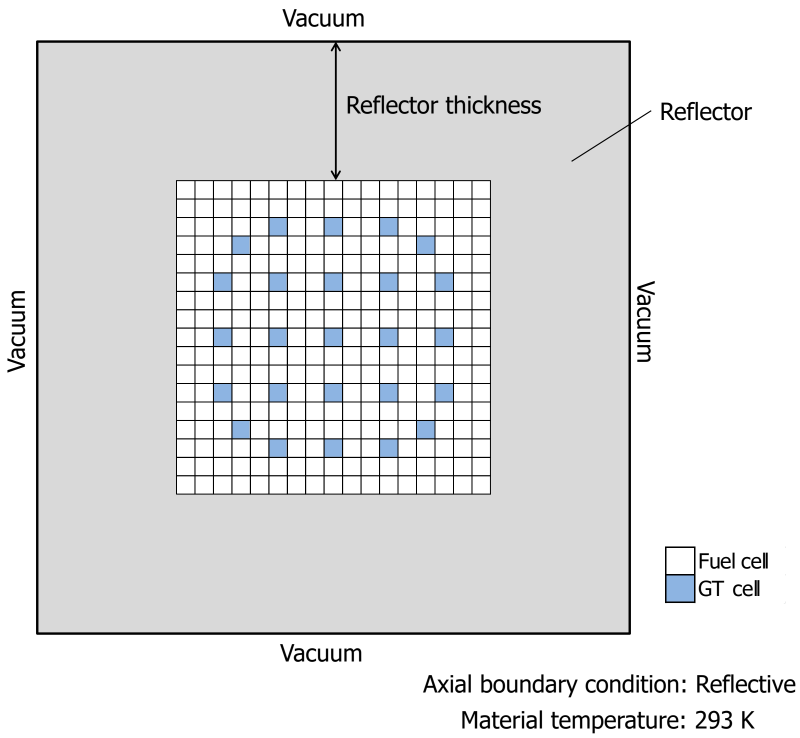
Generally, among the participants, a good agreement of calculation results was observed. This means that the quality and performance of calculation tools and nuclear data libraries used by the participants was consistent. The differences observed among the neutron multiplication factors and the reflector effects are moderate and can be explained based on the experience of the burn-up credit criticality safety benchmarks carried out in the past two decades, which confirms the applicability of the modern criticality safety evaluation systems to the reflector conditions related to the direct disposal of the UNF.

1. Overview of benchmark specification

1.1. Fuel assembly specification

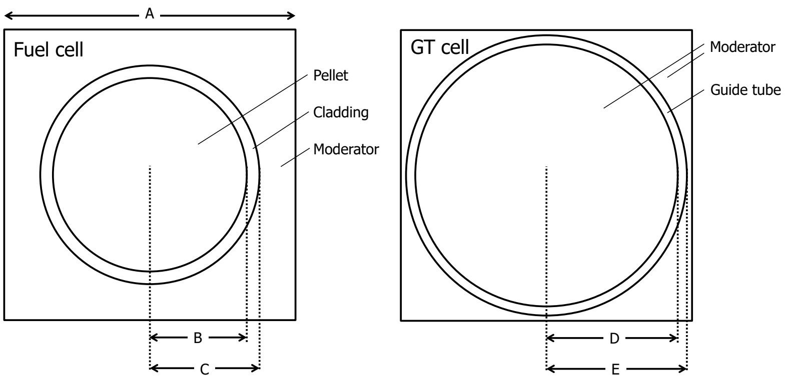
Figure 1.1 shows the system of a 17 × 17 type pressurised water reactor (PWR) fuel assembly with a reflector. This is a two-dimensional model of the fuel assembly. To simulate the infinite dimension in the axial direction, a reflective boundary condition is adopted while a vacuum boundary condition I s adopted in the radial direction. Both fuel cells and guide tube (GT) cells are modelled. A number of cases with different reflector materials and thicknesses was specified, as described in Sections 1.4 and 1.5 and in Appendix C.5. The specification of the fuel rod and the GT is shown in Figure 1.2. The moderator region, shown in Figure 1.2, is assumed to be filled with water or clay material containing water. Cases for fresh fuel are also considered to obtain comprehensive information on the reflector effect. The temperature of 293 K is assumed for all materials.

Figure 1.1 Schematic geometrical model for benchmark problem



Source: JAEA, 2019.

Figure 1.2 Geometrical specification of fuel rod and guide tube



Symbol		
A	Fuel rod pitch (cm)	1.265
	Fuel rod	
B	Radius of pellet (cm)	0.412
C	Outer radius of cladding tube (cm)	0.476
	Guide tube	
D	Inner radius of tube (cm)	0.570
E	Outer radius of tube (cm)	0.610

Source: Yamamoto et al., 2002.

1.2. Moderator and cladding

The compositions of the moderator region and cladding tube are shown in Table 1.1. The composition of the cladding tube is assumed to be natural zirconium rather than zircalloy for simplicity. The grid spacer is also neglected for simplicity.

Table 1.1 Specification of moderator and cladding tube

		Moderator		Cladding tube
Material	Element	H_2O	SiO_2 (wet)	Zr-nat
Number density (#/barn/cm)	H	6.6742E-02	2.7190E-02	–
	O	3.3371E-02	4.5668E-02	–
	Si	–	1.6037E-02	–
	Zr	–	–	4.3108E-02

Source: JAEA, 2019.

1.3. Fuel composition

In this benchmark, PWR UO_2 fuel of 4.5 wt% ^{235}U enrichment is chosen. The nuclide number density of the fresh fuel is shown in Table 1.2.

Table 1.2 Nuclide number density of the fresh fuel

	Number density (#/barn/cm)
^{235}U	1.0468E-03
^{238}U	2.1935E-02
^{16}O	4.5963E-02

Source: JAEA, 2019.

Several combinations of assembly burn-up values and decay times are specified in the benchmark. The representative burn-up values, 30 and 45 GWd/t, are selected. 45 GWd/t is selected as the usual spent nuclear fuel and 30 GWd/t is considered as the intermediate case in order to understand the influence of the burn-up value on the reflector effect. In the used fuel case of this benchmark, the concept of burn-up credit is taken into account and the fuel composition in a fuel assembly is assumed to be uniform for simplicity.

To prepare the burned fuel compositions, burn-up calculations were conducted by ORIGEN2.2 [2,3] adopting ORLIBJ40 [4] cross-section library. In this benchmark, 13 actinides and 15 fission products are adopted for the criticality calculation, these fuel nuclides are listed in Table 1.3. These are the same nuclides selected in the past burn-up credit criticality safety benchmarks prepared by the NEA [5]. In addition to that, ^{233}U is added considering the accumulation of ^{233}U by the radioactive decay of ^{241}Am and ^{237}Np. The number densities of used fuel compositions at burn-up values of 30 GWd/t and 45 GWd/t are specified in Tables 1.4 and 1.5, respectively.

Table 1.3 Nuclide list used in the criticality calculation in this benchmark

	Nuclide list
13 Actinides	^{233}U, ^{234}U, ^{235}U, ^{236}U, ^{238}U, ^{237}Np, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu, ^{242}Pu, ^{241}Am, ^{243}Am
15 Fission products	^{95}Mo, ^{99}Tc, ^{101}Ru, ^{103}Rh, ^{109}Ag, ^{133}Cs, ^{147}Sm, ^{149}Sm, ^{150}Sm, ^{151}Sm, ^{152}Sm, ^{143}Nd, ^{145}Nd, ^{153}Eu, ^{155}Gd

Source: JAEA, 2019.

Table 1.4 Number density of 30 GWd/t burned fuel

30 G Wd/t (#/barn/cm)			
Decay time (year)	0.00E+00	3.00E+04	2.00E+07
Actinide			
^{233}U	3.5590E-11	3.1581E-07	4.0816E-09
^{234}U	6.3908E-08	2.4520E-06	1.1776E-06
^{235}U	4.4013E-04	5.1974E-04	5.6688E-04
^{236}U	1.0735E-04	1.4487E-04	8.1136E-05
^{238}U	2.1492E-02	2.1492E-02	2.1431E-02
^{237}Np	8.5259E-06	3.4994E-05	5.4966E-08
^{238}Pu	2.2935E-06	0.0000E+00	0.0000E+00
^{239}Pu	1.3530E-04	5.8346E-05	2.1611E-15
^{240}Pu	3.9089E-05	1.6514E-06	1.3861E-14
^{241}Pu	2.5945E-05	1.4039E-12	0.0000E+00
^{242}Pu	5.9083E-06	5.5910E-06	0.0000E+00
^{241}Am	6.2531E-07	4.2499E-11	0.0000E+00
^{243}Am	8.4105E-07	5.01147E-08	6.6060E-16
Fission product			
^{95}Mo	3.4410E-05	4.1747E-05	4.1747E-05
^{99}Tc	4.1123E-05	3.7478E-05	0.0000E+00
^{101}Ru	3.8223E-05	3.8224E-05	3.8224E-05
^{103}Rh	2.1211E-05	2.3714E-05	2.3714E-05
^{109}Ag	2.6601E-06	2.6665E-06	2.6665E-06
^{133}Cs	4.3335E-05	4.3874E-05	4.3874E-05
^{147}Sm	2.3798E-06	1.0535E-05	1.0534E-05
^{149}Sm	1.1202E-07	1.6000E-07	1.6000E-07
^{150}Sm	9.4144E-06	9.4145E-06	9.4145E-06
^{151}Sm	4.8645E-07	0.0000E+00	0.0000E+00
^{152}Sm	3.5278E-06	3.5282E-06	3.5282E-06
^{143}Nd	3.1569E-05	3.2553E-05	3.2554E-05
^{145}Nd	2.4498E-05	2.4510E-05	2.4510E-05
^{153}Eu	3.3567E-06	3.3870E-06	3.3870E-06
^{155}Gd	1.9812E-09	2.0368E-07	2.0368E-07
Others			
^{16}O	4.5960E-02	4.5960E-02	4.5960E-02

Source: JAEA, 2019.

Table 1.5 Number density of 45 GWd/t burned fuel

30 G Wd/t (#/barn/cm)			
Decay time (year)	0.00E+00	3.00E+04	2.00E+07
Actinide			
^{233}U	3.5120E-11	4.9070E-07	6.3435E-09
^{234}U	1.0024E-07	6.4456E-06	1.1636E-06
^{235}U	2.5992E-04	3.4617E-04	4.0208E-04
^{236}U	1.3269E-04	1.8831E-04	1.0563E-04
^{238}U	2.1227E-02	2.1227E-02	2.1176E-02
^{237}Np	1.4257E-05	5.4379E-05	8.5427E-08
^{238}Pu	6.2772E-06	0.0000E+00	0.0000E+00
^{239}Pu	1.4480E-04	6.3700E-05	5.9639E-14
^{240}Pu	5.6911E-05	2.4471E-06	7.8754E-14
^{241}Pu	3.9099E-05	1.3414E-11	0.0000E+00
^{242}Pu	1.5184E-05	1.4373E-05	0.0000E+00
^{241}Am	1.1751E-06	4.0607E-10	0.0000E+00
^{243}Am	3.2111E-06	1.9136E-07	1.8230E-14
Fission product			
^{95}Mo	5.2295E-05	5.9184E-05	5.9184E-05
^{99}Tc	5.8734E-05	5.3436E-05	0.0000E+00
^{101}Ru	5.6898E-05	5.6900E-05	5.6900E-05
^{103}Rh	2.9856E-05	3.2651E-05	3.2651E-05
^{109}Ag	4.8499E-06	4.8592E-06	4.8592E-06
^{133}Cs	6.0902E-05	6.1439E-05	6.1439E-05
^{147}Sm	3.8097E-06	1.2592E-05	1.2590E-05
^{149}Sm	1.0999E-07	1.6246E-07	1.6246E-07
^{150}Sm	1.4649E-05	1.4694E-05	1.4649E-05
^{151}Sm	5.6117E-07	0.0000E+00	0.0000E+00
^{152}Sm	4.5354E-06	4.5359E-06	4.5359E-06
^{143}Nd	4.1013E-05	4.1949E-05	4.1950E-05
^{145}Nd	3.4106E-05	3.4117E-05	3.4117E-05
^{153}Eu	5.6088E-06	5.6507E-06	5.6507E-06
^{155}Gd	3.7644E-09	3.8253E-07	3.8253E-07
Others			
^{16}O	4.5960E-02	4.5960E-02	4.5960E-02

Source: JAEA, 2019.

1.4. Reflector material specification

Three types of reflector materials are considered in this benchmark. First, SiO_2 of 1.6 g/cc dry density is chosen. No water content is assumed for this material. The dry density corresponds to the material consisting of 70% bentonite and 30% silica sand, which is a candidate for the clay buffer material in the geological disposal [6]. The chemical composition of this mixture is assumed to be 100% SiO_2 for simplicity. This assumption, i.e. neglecting neutron absorption of other chemical compositions in the soil, is assumed to be conservative for criticality safety evaluation. In the second reflector case, a more realistic material model of SiO_2 in a water-saturated condition is used. In this case, the void space in the SiO_2 is completely filled with water. In the final reflector case, full density water is used in order to compare the reflector effect between SiO_2 and the water. The specifications of the three types of the reflector materials are shown in Table 1.6.

Table 1.6 Specification of reflector materials

Material	SiO_2 (dry)	SiO_2 (wet)	H_2O
Density (g/cc)			
SiO_2	1.6	1.6	–
H_2O	0	0.4067	0.9983
Number density (#/barn/cm)			
H	–	2.7190E-02	6.6742E-02
O	3.2073E-02	4.5668E-02	3.3371E-02
Si	1.6037E-02	1.6037E-02	–

Source: JAEA, 2019.

1.5. Case ID and combination of parameters

Several reflector thicknesses were selected. The calculation cases and the corresponding case IDs for fresh fuel case and used fuel case are shown in Tables 1.7 and 1.8, respectively. The calculation cases for larger thickness of wet SiO_2 and water were omitted since the neutron multiplication factors remain unchanged in such cases.

Table 1.7 Calculation case and case ID for fresh fuel case

Moderator material	Reflector material	Reflector thickness						
		0 cm	10 cm	20 cm	40 cm	60 cm	90 cm	120 cm
H_2O	SiO_2 (dry)	zero	sd10	sd20	sd40	sd60	sd90	sd120
	SiO_2 (wet)		sw10	sw20	sw40	sw60	-	-
	H_2O		lw10	lw20	lw40	-	-	-
SiO_2 (wet)	SiO_2 (wet)	zeros	sw10s	sw20s	sw40s	sw60s	-	-

Source: JAEA, 2019.

Table 1.8 Calculation case and case ID for used fuel case

Fuel ID	Burnup	Decay time	Reflector material / Reflector thickness							
			0 cm	SiO_2 (dry)			SiO_2 (wet)		H_2O	
				10 cm	40 cm	120 cm	10 cm	40 cm	10 cm	40 cm
a	30 GWd/t	0 year	a-zero	a-sd10	a-sd40	a-sd120	a-sw10	a-sw40	a-lw10	a-lw40
b		30,000 year	b-zero	b-sd10	b-sd40	b-sd120	b-sw10	b-sw40	b-lw10	b-lw40
c		20 million year	c-zero	c-sd10	c-sd40	c-sd120	c-sw10	c-sw40	c-lw10	c-lw40
d	45 GWd/t	0 year	d-zero	d-sd10	d-sd40	d-sd120	d-sw10	d-sw40	d-lw10	d-lw40
e		30,000 year	e-zero	e-sd10	e-sd40	e-sd120	e-sw10	e-sw40	e-lw10	e-lw40
f		20 million year	f-zero	f-sd10	f-sd40	f-sd120	f-sw10	f-sw40	f-lw10	f-lw40

Source: JAEA, 2019.

1.6. Requested results

The following data were requested for the fresh fuel cases. The definitions of these data are described below the following items:

i. effective neutron multiplication factor (k_{eff});

ii. reaction rates inside the reflector region for ^{16}O scattering, ^{28}Si scattering, ^{28}Si capture, ^{1}H scattering and ^{1}H capture;

iii. ratio of the absorption rate to the production rate in the system;

iv. thermal spectrum index in the fuel assembly region.

The reaction rates in the requested data (ii) were defined to be integrated over the reflector region and to be normalised by the production rate integrated over the whole system (i.e. neutron source in the system). The reaction rates of ^{16}O scattering, ^{28}Si scattering, ^{28}Si capture, ^{1}H scattering and ^{1}H capture inside the reflector region were defined as follows:

$$R_s^{\text{O-16}} = \frac{\iint_{V_R} \Sigma_s^{\text{O-16}} \phi(\vec{r}, E) dVdE}{P} \quad (1)$$

$$R_s^{\text{Si-28}} = \frac{\iint_{V_R} \Sigma_s^{\text{Si-28}} \phi(\vec{r}, E) dVdE}{P} \quad (2)$$

$$R_c^{\text{Si-28}} = \frac{\iint_{V_R} \Sigma_c^{\text{Si-28}} \phi(\vec{r}, E) dVdE}{P} \quad (3)$$

$$R_s^{\text{H-1}} = \frac{\iint_{V_R} \Sigma_s^{\text{H-1}} \phi(\vec{r}, E) dVdE}{P} \quad (4)$$

$$R_c^{\text{H-1}} = \frac{\iint_{V_R} \Sigma_c^{\text{H-1}} \phi(\vec{r}, E) dVdE}{P} \quad (5)$$

Where:

$$P = \iint_{V_{FA}+V_R} \nu\Sigma_f \phi(\vec{r}, E) dVdE$$

Here, V_R and V_{FA} are the volume of reflector and fuel assembly, $\phi(\vec{r},E)$ is neutron flux, ν is the number of neutrons per fission and Σ^i_f, Σ^i_s and Σ^i_c are macroscopic fission, scattering and capture cross-section for nuclide i. Scattering cross-section means the total of elastic and inelastic scattering cross-section.

The ratio of the absorption rate to the production rate (A/P) in the requested data (iii) is defined as follows:

$$\frac{A}{P}=\frac{\iint_{V_{FA}+V_R}\Sigma_a\phi(\vec{r},E)dVdE}{\iint_{V_{FA}+V_R}\nu\Sigma_f\phi(\vec{r},E)dVdE} \qquad (6)$$

Here, A is the absorption rate and P is the production rate in the whole system. This value could be used to calculate the probability of the neutron leakage from the system. The ratio of the leakage rate (L) to the production rate (P) calculated by the following equation is used for comparison because this value is significant to investigate the mechanism of the reflector effect.

$$\frac{L}{P}=\frac{1}{k_{eff}}-\frac{A}{P} \qquad (7)$$

Where this equation is derived from the following fundamental k_{eff} definition.

$$k_{eff}=\frac{P}{A+L}$$

In this benchmark, the co-ordinator calculated the ratio of the leakage rate to the production rate (L/P) using the data from the participants.

The thermal spectrum index in the requested data is defined to be the ratio of the thermal flux to the total flux, where the boundary energy is set to be 0.625eV. The thermal spectrum index in the fuel assembly region is defined as follows:

$$SI_{th}=\frac{\phi_{thermal}}{\phi_{total}}=\frac{\int_{thermal}\int_{V_{FA}}\phi(\vec{r},E)dVdE}{\int_{thermal+fast}\int_{V_{FA}}\phi(\vec{r},E)dVdE} \qquad (8)$$

Here, V_{FA} involves all components inside the fuel assembly (i.e. fuel pellets, cladding tubes, guide tubes and moderator regions).

2. Participants and analysis methods

Nineteen sets of results from fifteen participants of nine institutes in eight countries were received for this benchmark. Table 2.1 shows the list of the final participants. The list includes the names of the participants, institutes, countries and the adopted computer codes and nuclear data libraries. The countries and the institutes of the participants are summarised in Table 2.2.

The nuclear data and computer codes are summarised in Table 2.3, which shows that 12 cases use Evaluated Nuclear Data File (ENDF) (ENDF/B-V (44 group), ENDF/B-V (238 group), ENDF/B-VI.8, ENDF/B-VII.0 and ENDF/B-VII.1), 4 cases use JEF (JEF-2.2, Joint Evaluated Fission and Fusion File (JEFF-3.1.0 and JEFF-3.1.2), 2 cases use Japanese Evaluated Nuclear Data Library (JENDL) (JENDL-3.2 and JENDL-4.0) and one case uses Chinese Evaluated Nuclear Data Library (CENDL) (CENDL-3.1). Thus, the most popular nuclear data library is ENDF and SCALE is the most selected computer code by the participants. As the evaluation of nuclear data has been carried out within an international co-operation, the evaluated data are shared among ENDF, JENDL and JEFF. Hence, it should be noted that it is not a simple task to find the exact reason for the observed differences among the results adopting different libraries. CENDL is used by only one participant, which might be the first time that CENDL is used in the international benchmarks under Working Party on Nuclear Criticality Safety (WPNCS). It should also be noted that older libraries, such as ENDF/B-V and JENDL-3.2 are still being used.

Concerning the thermal scattering law (TSL), the adopted TSL was checked by each user. The Institut de Radioprotection et de Sûreté Nucléaire (IRSN) uses the TSL from JEFF-3.1 for H_2O. GRS and EMS use the TSL of H_2O from the standard ENDF/B-base SCALE cross-section libraries. E. Mennerdahl Systems (EMS) uses the TSL of hydrogen and uranium in the SCALE system. JAEA uses the TSL of hydrogen as of H_2O from JENDL-4.0. According to the authors, the appropriate TSL was used in each calculation. However, there were no participants using the TSL for SiO_2.

Concerning computer codes, several versions of the SCALE code system were used. Additionally, computer codes such as MVP-II, MONK, MCNP and MORET5B2 were also used by the participants. Continuous energy (CE) Monte Carlo codes are widely used and independent codes have been developed in several institutes, which allows for comparing independent results.

Table 2.1 List of participants EGUNF Phase I Benchmark

ID	Participants	Institutes	Country	Code	Nuclear data
JAEA	K. Yamamoto, K. Suyama M. Kataoka	JAEA	Japan	MVP-II.0.23	JENDL-4.0
GRS1 GRS2 GRS3 GRS4	E. Peters R. Kilger	GRS	Germany	SCALE-6.1.2	ENDF/B-V*1 ENDF/B-V*2 ENDF/B-VI.8 ENDF/B-VII.0
VUJE	V. Chrapciak	VUJE	Slovak Republic	SCALE-6.1.2	ENDF/B-VII.0
EDF1 EDF2 EDF3 EDF4 EDF5 EDF6	D. Putley	EDF	United Kingdom	MONK9A MONK10A	JEF-2.2*3 JEF-2.2*3 JENDL-3.2 JEFF-3.1.2 ENDF/B-VII.0 CENDL-3.1
EMS1 EMS2	D. Mennerdahl	EMS	Sweden	SCALE-6.2b4	ENDF/B-VII.0*4 ENDF/B-VII.1
BFS	B. Ruprecht, I. Reiche	BFS	Germany	SCALE-6.1.3	ENDF/B-VII.0
NCBJ1 NCBJ3	A. Boettcher L. Koszuk M. Klisinka	NCBJ	Poland	MCNPX-2.7.0 SCALE-6.1.3	ENDF/B-VII.0 ENDF/B-VII.0
IRSN	L. Jutier	IRSN	France	MORET5B2	JEFF-3.1.0
EK	G. Hordosy	EK	Hungary	MCNP5-1.60	ENDF/B-VII.0

*1: Energy group: 44 groups.
*2: Energy group: 238 groups.
*3: Elements of oxygen and hydrogen are treated in different way from case EDF1.
*4: Energy group: 238 groups.

Source: JAEA, 2019.

Table 2.2 Countries and institutes

Country	Institutes
Japan	JAEA
Germany	GRS and BFS
Slovak Republic	VUJE
United Kingdom	EDF
Sweden	EMS
Poland	NCBJ
France	IRSN
Hungary	EK

Source: JAEA, 2019.

Table 2.3 Nuclear data and computer codes applied to the benchmark calculations

Nuclear data	Computer code (Case ID in Table 2.1)	Number of results
ENDF/B-V(44 group)	SCALE-6.1.2 (GRS1)	1
ENDF/B-V(238 group)	SCALE-6.1.2 (GRS2)	1
ENDF/B-VI	SCALE-6.1.2 (GRS3)	1
ENDF/B-VII.0	SCALE-6.1.2 (GRS4), SCALE-6.1.2 (VUJE), MONK10A (EDF5), SCALE-6.2b4 (EMS2), SCALE-6.1.3 (BFS), MCNPX-2.7.0 (NCBJ1), SCALE-6.1.3 (NCBJ3), MCNP5-1.60 (EK)	8
ENDF/B-VII.1	SCALE-6.2b4 (EMS1)	1
JEF-2.2	MONK9A (EDF1, EDF2)	2
JEFF-3.1.0	MORET5B2 (IRSN)	1
JEFF-3.1.2	MONK10A (EDF4)	1
JENDL-3.2	MONK9A (EDF3)	1
JENDL-4.0	MVP-II.0.23 (JAEA)	1
CENDL-3.1	MONK10A (EDF6)	1

Source: JAEA, 2019.

3. Results of the participants

All the participants provided the calculation results for all cases. However, the results of the reaction rates of EMS1 were not submitted because of the limitations of the code and data library. The reflector effect factor (R_{eff}) is estimated from the effective neutron multiplication factor (k_{eff}) results as follows:

$$R_{eff} = \frac{k_R - k_0}{k_0} \times 100 \qquad (1)$$

Here, k_R is k_{eff} with reflector and k_0 is k_{eff} without reflector. The average value (Ave.) standard deviation (SD) and the relative standard deviation (RSD) of requested data are calculated using the following equations:

$$Ave. = \frac{1}{n}\sum_{i=1}^{n} x_i \qquad (2)$$

$$SD = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - Ave.)^2} \qquad (3)$$

$$RSD(\%) = \frac{SD}{Ave.} \times 100 \qquad (4)$$

All the results of k_{eff} and the calculated average, SD and RSD sent from the participants are summarised in Appendix A and in Tables A.1 to A.7.

3.1. Effective neutron multiplication factor

Appendix A, Figures A.1 through A.22 plot the neutron multiplication factor against the reflector thickness. The difference of k_{eff} between each participant and the average of all participants is summarised in Tables A.8 through A.14 and presented in Figures A.23 through A.44.

Figures A.1 to A.22 show that the value of k_{eff} increases with the reflector thickness irrespective of the fuel burn-up value and the cooling time. The increase in the neutron multiplication factor for the dry SiO_2 reflector cases is larger than the cases of the wet SiO_2 reflector because of the neutron absorption effect of ^1H in wet SiO_2.

Table 3.1 summarises the Maxwellian-averaged neutron reaction cross-section data of JENDL-4 at 300 K of nuclides in the reflector materials of this benchmark. It shows that the neutron capture cross-section of ^1H is almost the double of that of natural silicon. The total cross-section of ^1H is 16 times larger than that of natural silicon. Hence, the reflector effect of H_2O is easily observed with a thin layer. The H_2O reflector effect is already saturated at around 15 cm, which is consistent with the use of 30 cm H_2O reflector (assumed to be an infinite reflector) as is usually adopted for the criticality safety assessment of nuclear materials.

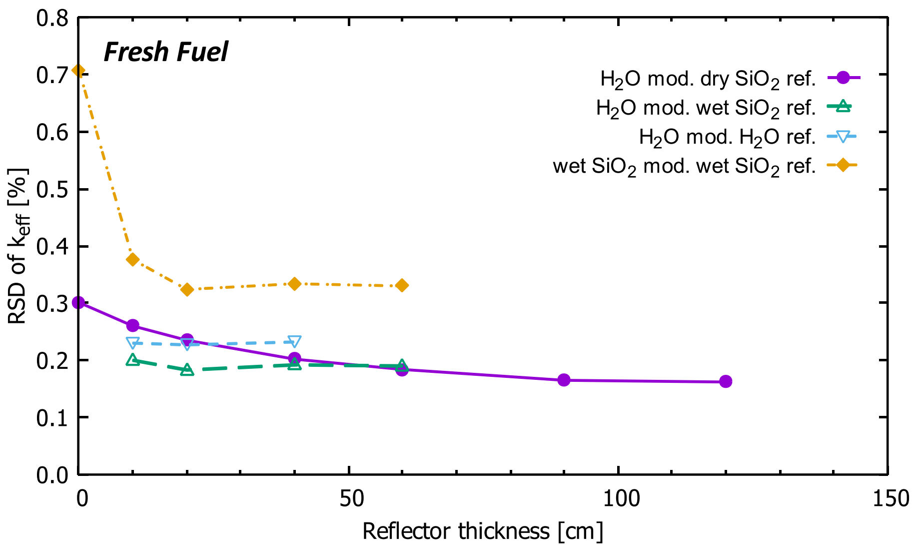
Table 3.1 Maxwellian-averaged cross-sections* at 300 K and natural abundance of isotopes in reflector materials of this benchmark**

Isotope	Capture [b]	Total [b]	Abundance [%]
^{1}H	332.0 [mb]	33.15	99.9885
^{16}O	190.0 [μb]	4.474	99.757
^{28}Si	169.3[mb]	2.418	92.2297
^{29}Si	120.0[mb]	3.089	4.6832
^{30}Si	107.2[mb]	2.929	3.0872
Natural Si	165.0[mb]	2.465	100.0

Source: *Shibata et al., 2011 [7]; **Rosman and Taylor, 1998 [8].

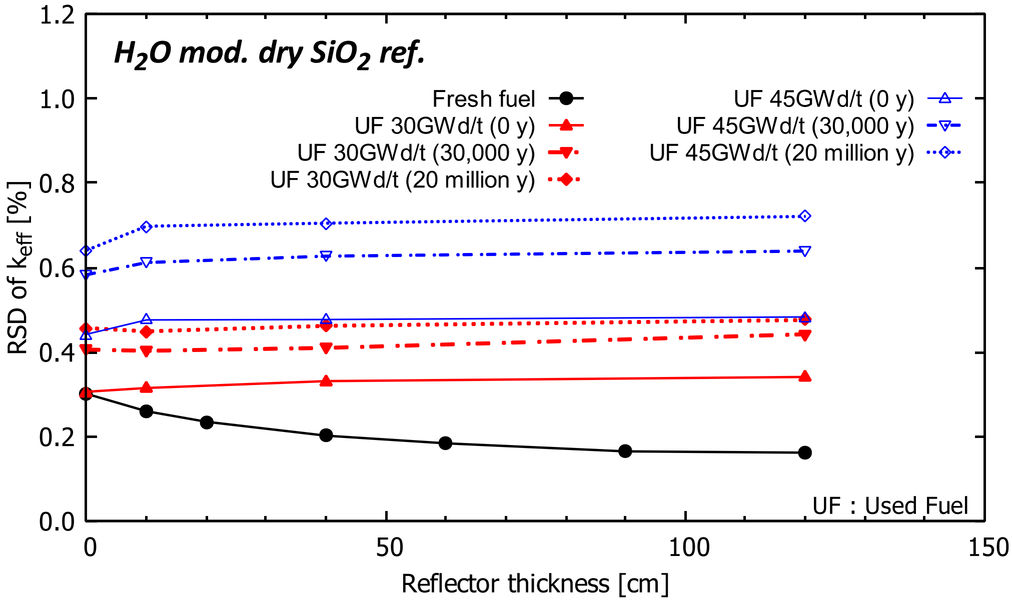
Figures 3.1 to 3.5 are the RSD of k_{eff}. The maximum RSD of k_{eff} is approximately 0.8%. RSD of k_{eff} is almost constant irrespective of the thickness of the reflector.

Figure 3.1 RSD of k_{eff} for fresh fuel case



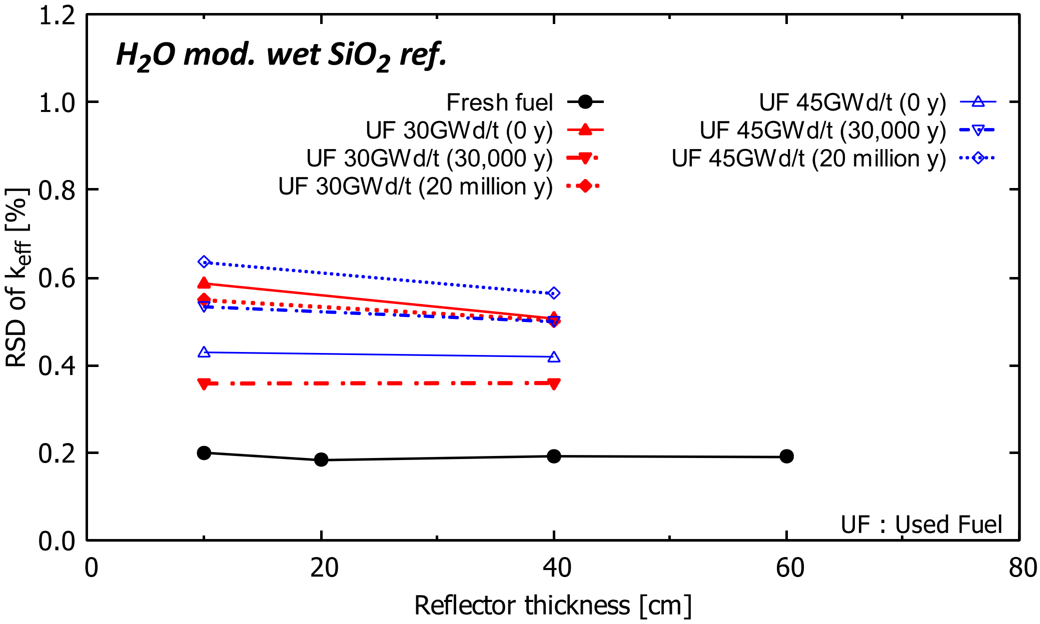
Source: JAEA, 2019.

Figure 3.2 RSD of k_{eff} of dry SiO_2 reflector



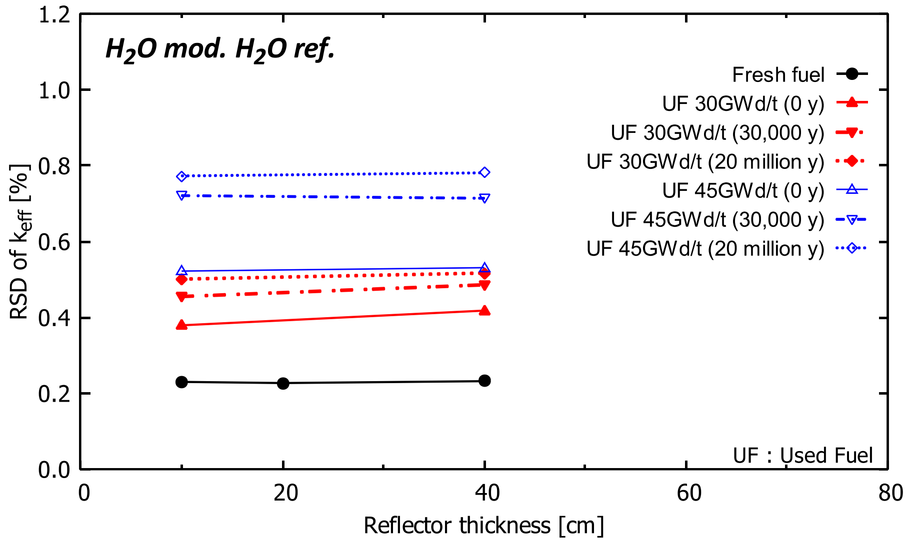
Source: JAEA, 2019.

Figure 3.3 RSD of k_{eff} of wet SiO_2 reflector



Source: JAEA, 2019.

Figure 3.4 RSD of k_{eff} of H_2O reflector



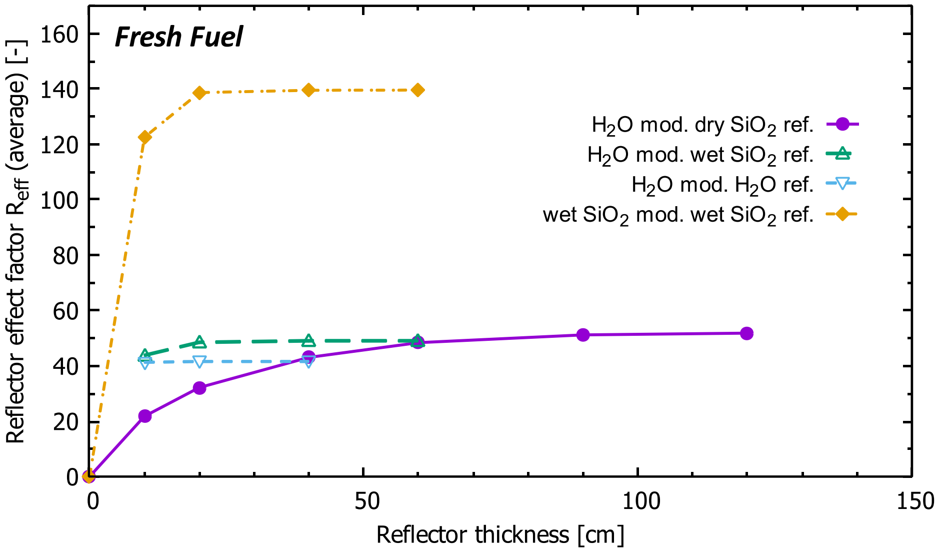
Source: JAEA, 2019.

3.2. Reflector effect on reactivity

The reflector effects are summarised in Tables A.15 to A.21 and presented in Figures A.45 to A.66. As shown in these tables and figures, all the k_{eff} values of the reflected systems are larger than that of the system without reflector. Hence, the reflector effect factor, i.e. R_{eff} is always positive in the cases considered in this benchmark calculation.

The R_{eff} initially increases with thickness to a point where essentially the reflector appears infinite to the neutron. As the thickness nears this point, the effect flattens and will eventually become constant. Figure 3.5 [9] compares the averaged R_{eff} factors in the cases using the fresh fuel composition. In the H_2O and wet SiO_2 reflected cases, the R_{eff} factor rapidly converged in constant values as the reflector thickness reaches to around 10-20 cm, while R_{eff} gradually increases until the reflector thickness reaches to around 100 cm in the dry SiO_2 reflected system. These results indicate that the reflector thickness of H_2O and wet SiO_2 about 20 to 30 cm may be sufficient to estimate the spent fuel criticality, when there is a certain amount of H_2O in the reflector. However, in the dry SiO_2 reflected condition, the reflector thickness of at least 100 cm is necessary [9]. The sufficient thickness of the dry SiO_2 reflector for criticality estimation from the viewpoint of neutron leakage behaviour will be discussed in Section 3.5.

Figure 3.5 Average R_{eff} in each moderator and reflector cases (fresh fuel)

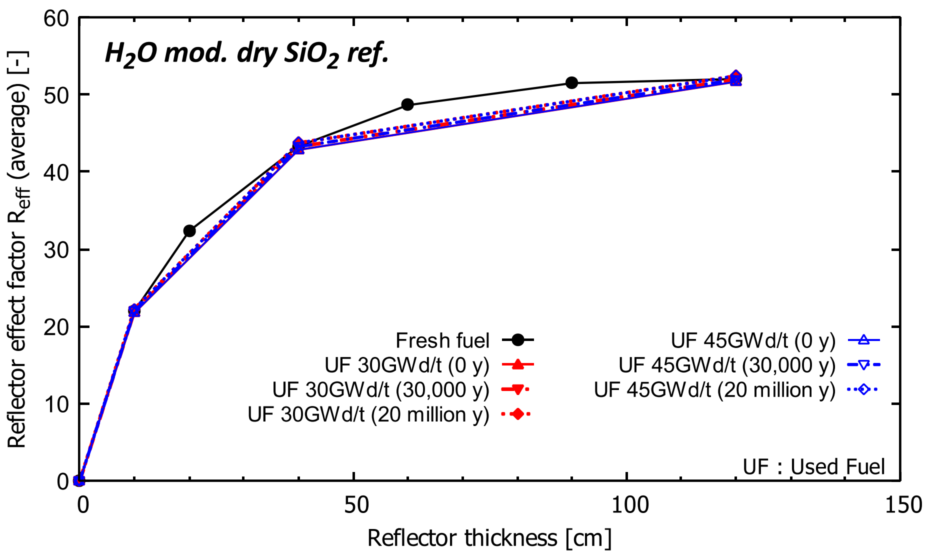


Source: Suyama et al., 2017.

If we use the wet SiO_2 reflector, the wet SiO_2 moderator gives a larger R_{eff} than the H_2O moderator because of the under-moderation for the case of the wet SiO_2 moderator system. This under-moderation is shown by the fact that the k_{eff} is less than 0.4 for the wet SiO_2 moderator without reflector case (fresh fuel composition).

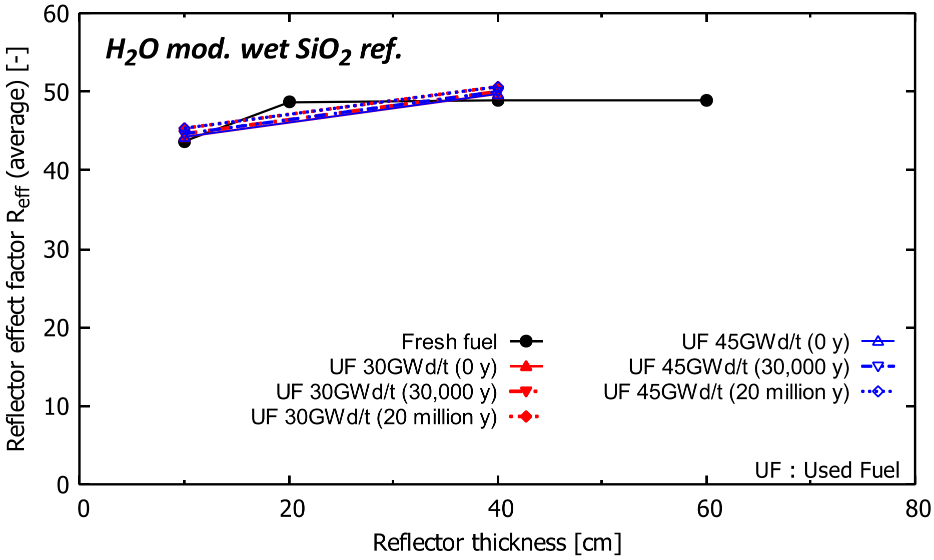
As shown in Figures 3.6 to 3.7, the R_{eff} values of the used fuel cases agree well with those of the fresh fuel cases irrespective of the reflectors, burn-up values and cooling time. Figures 3.10 to 3.11 present the RSD of R_{eff}. Any strong dependency of RSD of R_{eff} is not observed with the type of the reflector material, reflector thickness, or the moderator material [9]. The RSD of R_{eff} is less than 1.0% in the cases using the fresh fuel composition.

Figure 3.6 Average R_{eff} for used fuel cases with fresh fuel (H_2O moderator and dry SiO_2 reflector)



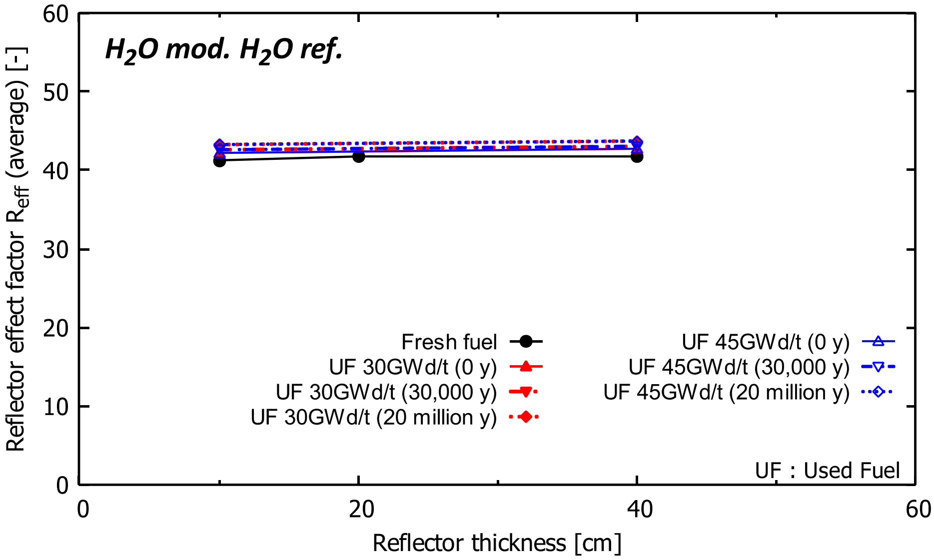
Source: JAEA, 2019.

Figure 3.7 Average R_{eff} for used fuel cases with fresh fuel (H_2O moderator and wet SiO_2 reflector)



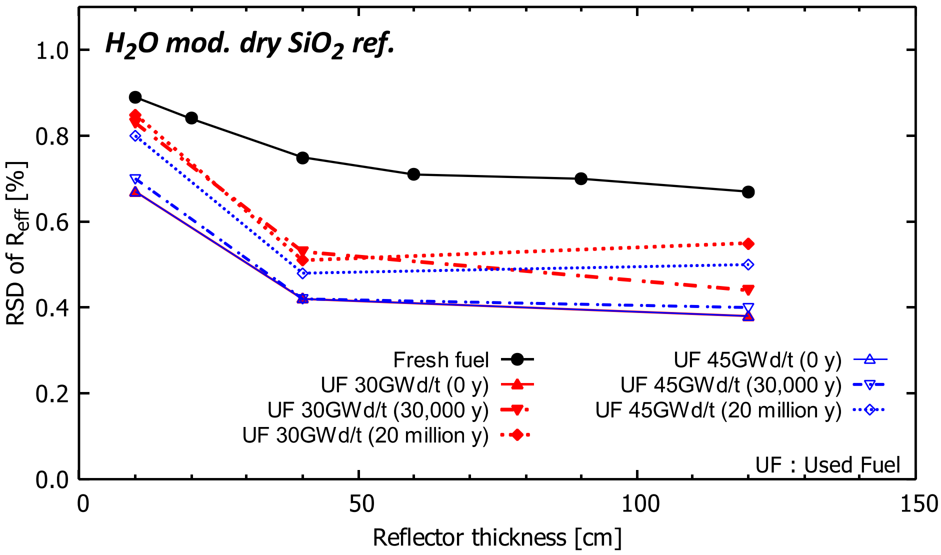
Source: JAEA, 2019.

Figure 3.8 Average R_{eff} for used fuel cases with fresh fuel (H_2O moderator and reflector)



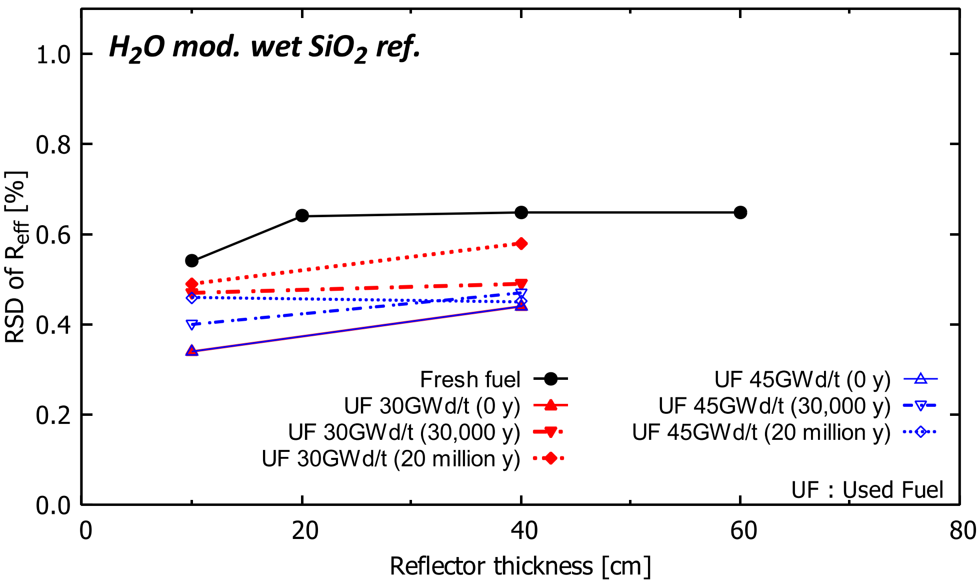
Source: JAEA, 2019.

Figure 3.9 RSDs of R_{eff} (H_2O moderator, dry SiO_2 reflector)



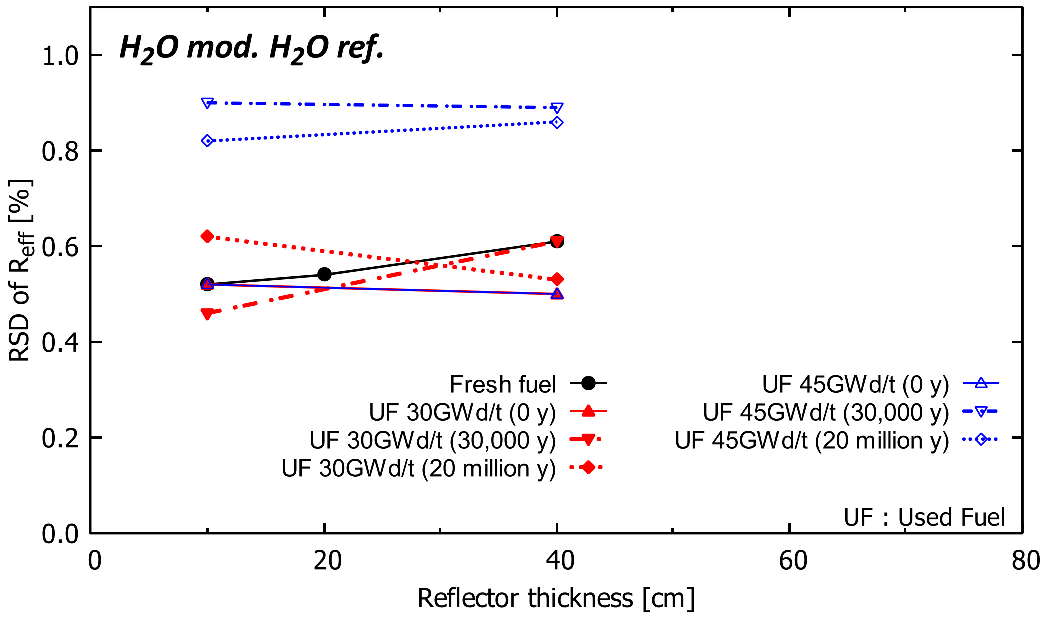
Source: JAEA, 2019.

Figure 3.10 RSDs of R_{eff} (H_2O moderator, wet SiO_2 reflector)



Source: JAEA, 2019.

Figure 3.11 RSDs of R_{eff} (H_2O moderator, H_2O reflector)



Source: JAEA, 2019.

3.3. Reaction rate in reflector region

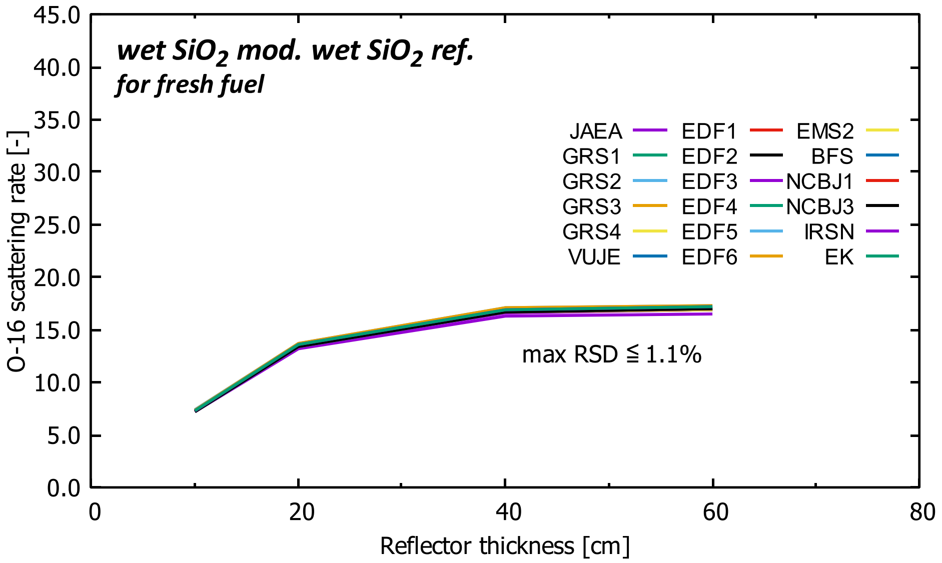
The reaction rates are summarised in Tables A.22 to A.26 and presented in Figures A.67 to A.78. The scattering reaction rates of ^{16}O agree well each other in the H_2O moderated systems, as shown in Figure 3.12. As shown in the figures of Appendix A, the maximum RSDs of this scattering rate are approximately 1.0%, respectively in the dry SiO_2, wet SiO_2 and H_2O reflected cases.

Both the scattering and capture reaction rates of ^{28}Si can be divided into two groups of higher and lower reaction rates, which could be seen in the case of the dry SiO_2 reflector, as shown in Figures 3.13 and 3.14. The higher reaction rates were given by Électricité de France (EDF1, EDF2, EDF3), Global Research for Safety (GRS1 and GRS2), which used old libraries such as JEF-2.2, JENDL-3.2 and ENDF-B/V and gave only natural silicon cross-section data. These results therefore gave the sum of ^{28}Si, ^{29}Si and ^{30}Si reaction rates, which is considered to be the cause of the higher reaction rates.

The cross-section data of all naturally occurring silicon isotopes are evaluated in JENDL-4.0. Hence, the reaction rates of each silicon isotope were evaluated by adopting MVP/JENDL-4.0 for the dry SiO_2 reflector case. Figures 3.15 and 3.16 show the comparison with other results. The sum of the reaction rates of all naturally occurring silicon isotopes evaluated by MVP/JENDL-4.0 are denoted by "Si-tot." with a triangular symbol and agree well with the reaction rates obtained by using the old data libraries giving natural silicon cross-section data. It can be assumed that the nuclear data of silicon in the older libraries JEF-2.2, JENDL-3.2 and ENDF-B/V are reliable as those in the current evaluated libraries.

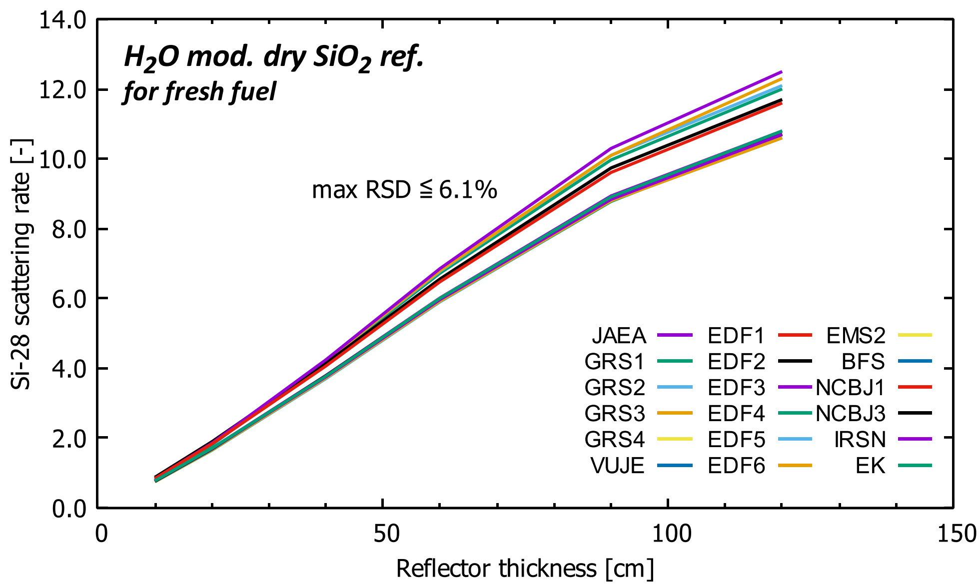
Figure 3.17 shows the ^{1}H reaction rate, which is in good agreement with each result obtained (RSD is less than 2%). Considering the importance of hydrogen reactions for slowing down of neutron, this result is reasonable.

Figure 3.12 ^{16}O scattering rate in the wet SiO_2 moderator and in the wet SiO_2 reflector system



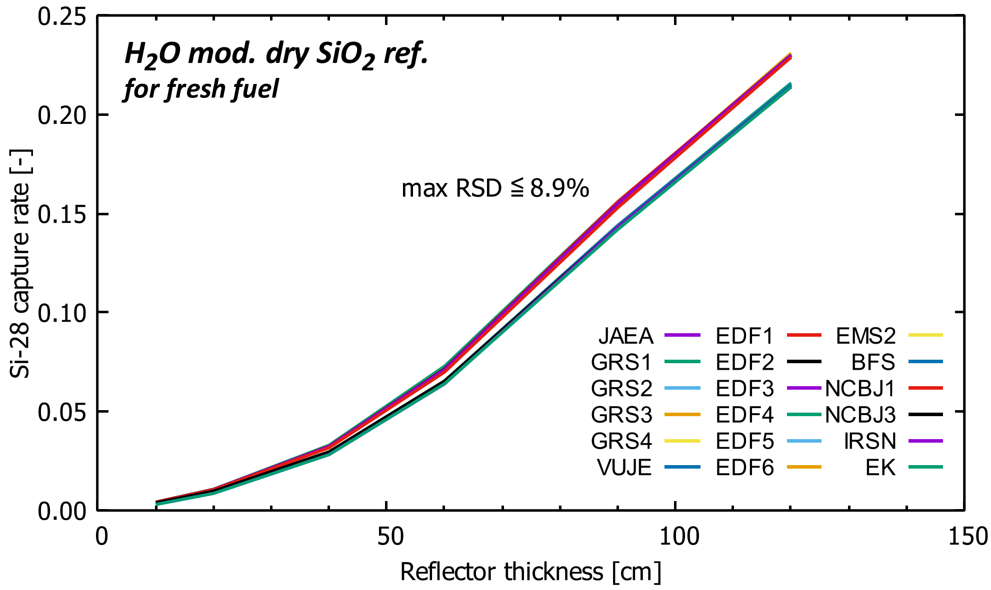
Source: JAEA, 2019.

Figure 3.13 ^{28}Si scattering rate in the H_2O moderator and the dry SiO_2 reflector system



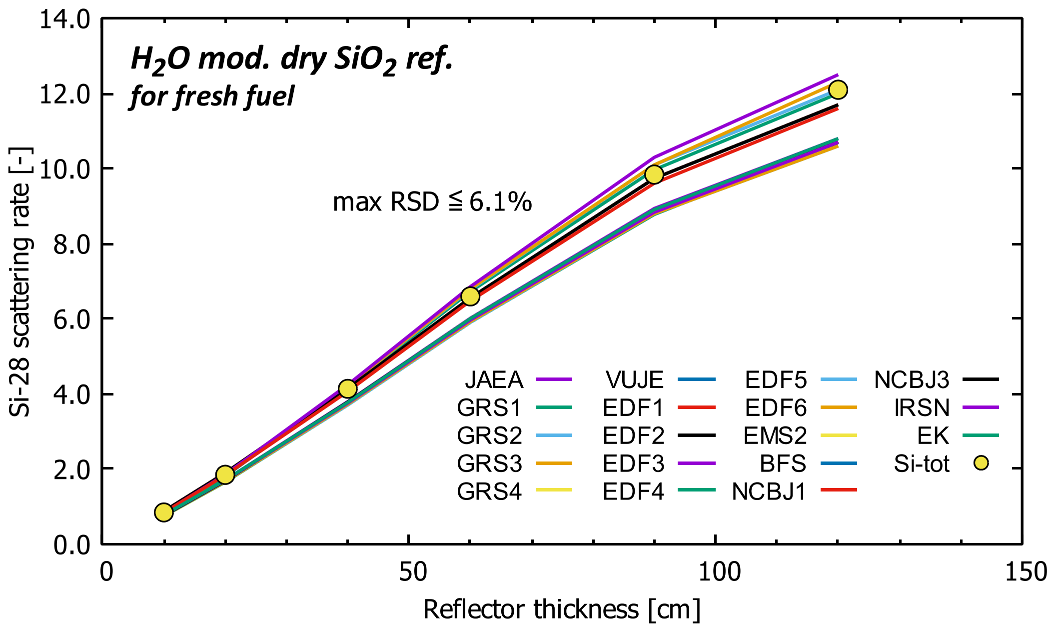
Source: JAEA, 2019.

Figure 3.14 ^{28}Si capture rate in the H_2O moderator and the dry SiO_2 reflector system



Source: JAEA, 2019.

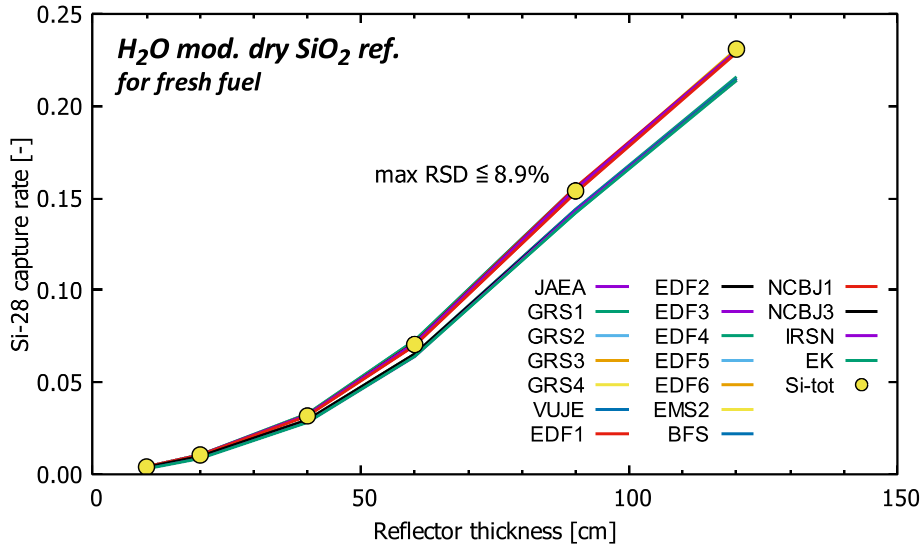
Figure 3.15 Comparison of the scattering reaction rates of silicon



Note: The triangle symbols are the estimation of the total scattering reaction rates by MVP/JENDL-4.0 (H_2O moderator and the dry SiO_2 reflector).

Source: JAEA, 2019.

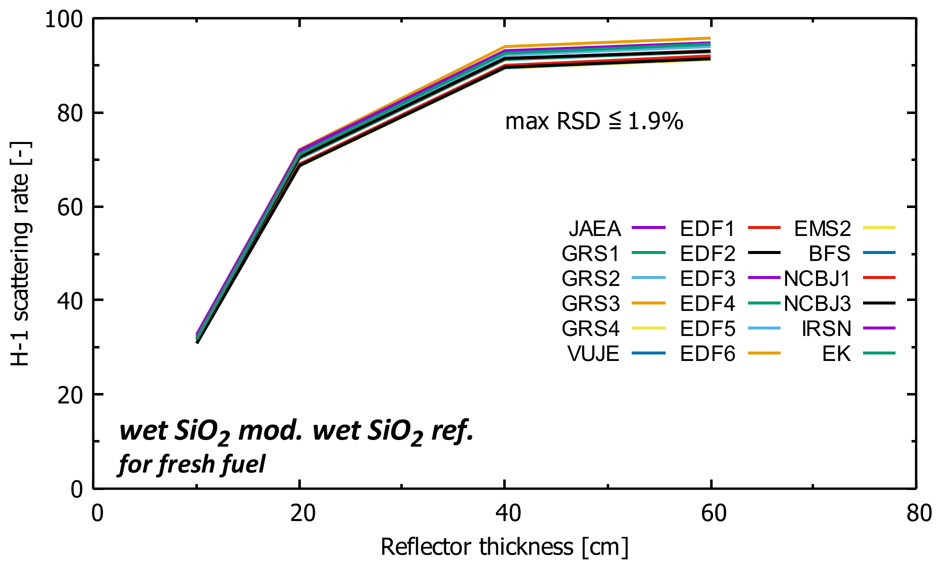
Figure 3.16 Comparison of the capture reaction rates of silicon



Note: The triangle symbols are the estimation of the total capture reaction rates by MVP/JENDL-4.0 (H_2O moderator and the dry SiO_2 reflector).

Source: JAEA, 2019.

Figure 3.17 H-1 scattering rate in the wet SiO_2 moderator, wet SiO_2 reflector system

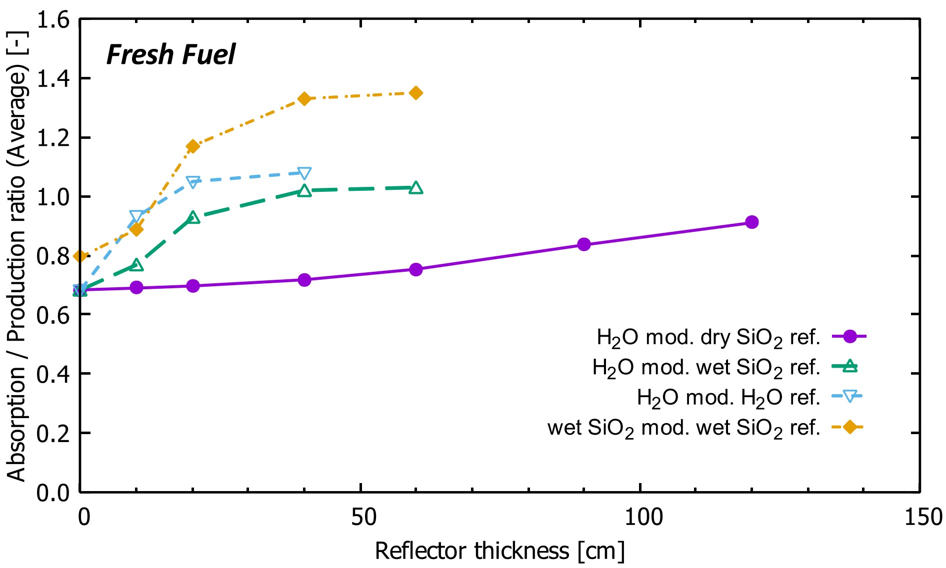


Source: JAEA, 2019.

3.4. Ratio of neutron absorption to production

The ratios of neutron absorption to production (A/P) are summarised in Table A.27 and presented in Figures A.79 to A.82. The ratio of reaction rates of neutron absorption to neutron production (A/P) in the whole system increases as increasing in the reflector thickness. Figure 3.18 compares the averaged A/P ratios of all the participants in each moderator/reflector system. In the H_2O and wet SiO_2 reflected system, the A/P ratio becomes greater than 1.0 when the reflector thickness reaches more than 40 cm and does not change with further increase in the reflector thickness. Contrary to these cases, A/P of dry SiO_2 reflector case is less than 1.0 and continuously increases up to the reflector thickness of 120 cm. These results indicate that the dry SiO_2 having sufficient (at least more than 120 cm) thickness would have better reflector effect than H_2O and the wet SiO_2. The RSD of A/P ratio was within about 0.5% in all the moderator and reflector cases and the results of the participants agreed well with each other. The reflector effect of SiO_2 will be discussed in Section 3.5.

Figure 3.18 Average neutron absorption/production rate ratios and their reflector thickness dependencies in each moderator and reflector system (fresh fuel composition)



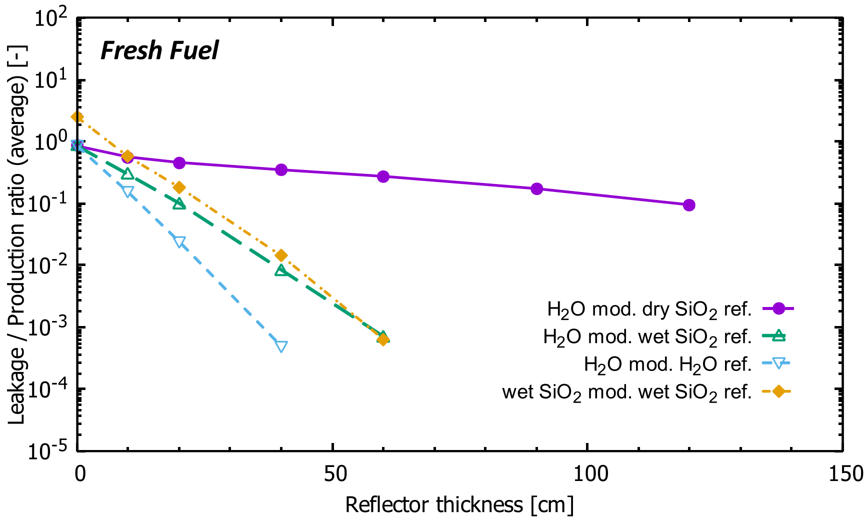
Source: JAEA, 2019.

3.5. Ratio of neutron leakage to production

The ratios of leakage to production (L/P) are summarised in Table A.28 and presented in Figures A.83 to A.86. The behaviour of the A/P ratio for the H_2O and the wet SiO_2 reflected system shown in Section 3.4 implies that a few neutrons could penetrate these reflectors beyond 40 cm thickness. Figure 3.19 presents the ratio of rates of the neutron leakage to the neutron production (L/P). It decreases to less than 0.01 if the thickness of these reflectors becomes more than about 40 cm.

On the other hand, L/P ratio was still about 0.1 in the dry SiO_2 reflector system even at the reflector thickness of 120 cm. This means that approximately 10% of produced neutrons leak (escape) from this system. Hence, the 120-cm reflector thickness might not be sufficient from the viewpoint of criticality estimation.

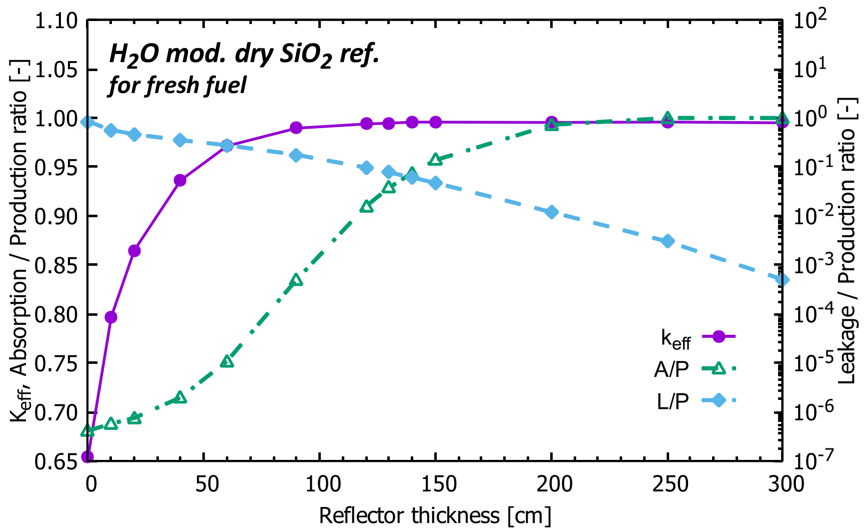
Figure 3.19 Average neutron leakage/production ratios and their reflector thickness dependencies in each moderator and reflector system (fresh fuel composition)



Source: JAEA, 2019.

To confirm this point, additional MVP/JENDL-4.0 calculations were carried out on the H_2O moderated system with the dry SiO_2 reflector having more than 120 cm thickness. As shown in Table A.29 and Figure 3.20, the k_{eff} converges and stays constant with a reflector thickness of more than 150 cm. In this situation, the L/P ratio becomes small, i.e. less than 0.05 and A/P keeps almost constant value irrespective of the increase in the reflector thickness. These results show that the dry SiO_2 is the best reflector material in this benchmark because of the small neutron capture cross-section and more than 150 cm reflector thickness should be used to use the dry SiO_2 reflector in the criticality safety evaluation.

Figure 3.20 Multiplication factor, absorption/production ratio and leakage/production ratio in the H_2O moderated dry SiO_2 reflected system with the reflector thickness of more than 120 cm (fresh fuel composition, MVP/JENDL-4.0 calculation)



Source: JAEA, 2019.

The RSD of the L/P ratio becomes very large when the value of L/P is less than about 0.01, as shown in Figures A.84 to 86. The L/P value of 0.01 means that the neutron leakage is only 1% of the produced neutron and this small leakage results in the large RSD of L/P. Actually, the SD value of L/P itself is less than 0.01 in these cases. The effect of such a small deviation on the multiplication factor is also expected to be less than 1%. When L/P is greater than 0.01, RSD of L/P is within about 5% in all the moderator and reflector cases. The SD of L/P is less than 0.01 in all the cases except for the value of 0.02 in the wet SiO_2 moderated case without reflector, where the neutron leakage was significantly larger than (up to 2.5 times) the neutron production.

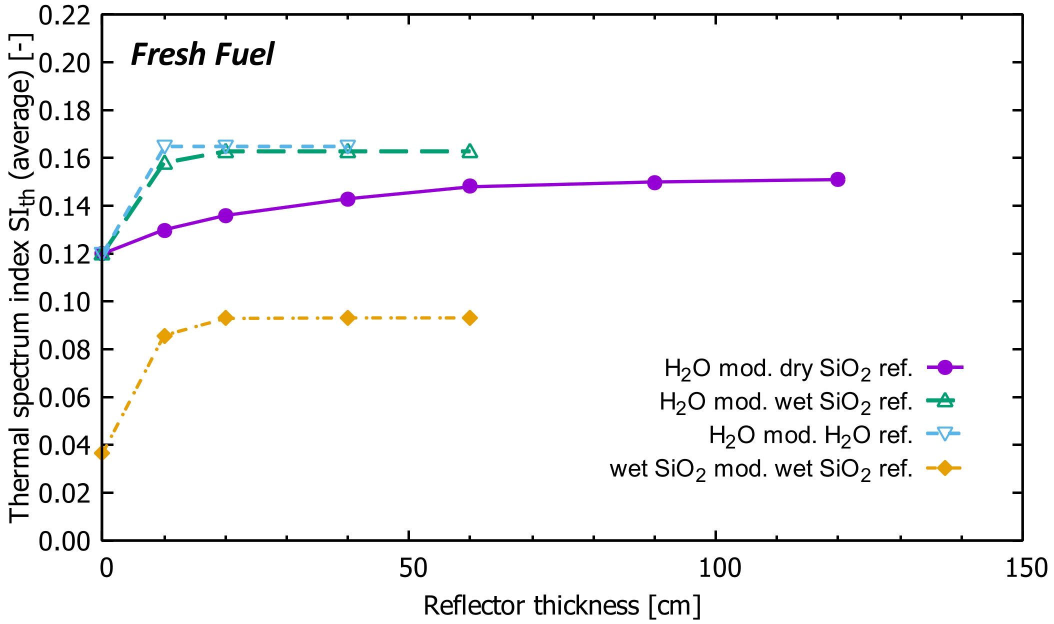
The observed agreement of the A/P ratio (within 0.5% RSD) and the L/P ratio (less than 1% SD) supports the credibility of the reflector effect calculations of the benchmark participants.

3.6. Thermal spectrum index

The thermal spectrum indices are summarised in Table A.30 and presented in Figures A.87 to A.90. The thermal spectrum index (SI_{th}) of the fuel assembly is approximately 0.12 in the H_2O moderated system without reflector and is less than 0.04 in the wet SiO_2 moderated case. These results are consistent with the smaller effective multiplication factor in the under-moderated wet SiO_2 moderator system.

Figure 3.21 shows that the SI_{th} value increases with the reflector thickness. In the same manner of k_{eff} and R_{eff}, SI_{th} converges to the constant value when the thickness of H_2O or the wet SiO_2 reflectors reaches around 10 to 20 cm. However, it keeps increasing up to approximately 100 cm for the dry SiO_2 reflector case. The RSD values of SI_{th} are generally within 2% and are about 5% in the wet SiO_2 moderated without reflector system.

Figure 3.21 Average thermal spectrum index versus reflector thickness for each moderator and reflector systems (fresh fuel composition)



Source: JAEA, 2019.

4. Conclusion

This benchmark aims at examining the reflector effect of materials involved in the direct disposal of used nuclear fuel. In this benchmark, silicon dioxide (SiO_2) is the focus for the inter-comparison objective since SiO_2 is a major component of materials proposed for backfill and of soil and rock. This benchmark consists of two parts addressing both fresh fuel and used fuel. For this purpose, a simple geometry model was adopted. In the used fuel cases, the concept of the burn-up credit was taken into account. The aim of the fresh fuel cases is to compare the SiO_2 reflector effect for a simplified condition and that of the used fuel cases is to compare SiO_2 reflector effect for the realistic fuel composition in the direct disposal.

This benchmark has fifteen participants from nine institutes of eight countries. Six computer codes (MVP, SCALE, MONK, MCNP, SERPENT, MORET) and some current major nuclear data libraries (ENDF/B, JENDL, JEFF) were used. CENDL was used by only one participant.

The k_{eff} value increases with the reflector thickness irrespective of fuel burn-up and cooling time. All the k_{eff} values of the reflected systems were larger than those of the corresponding system without reflector. As a result, the reflector effect on reactivity (R_{eff}) was always positive in the cases considered in this benchmark calculation. The RSD of k_{eff} was less than 0.8%.

In the H_2O and wet SiO_2 reflected cases, the R_{eff} rapidly converged to a constant value when the reflector thickness reached around 10 to 20 cm, while R_{eff} gradually increased until the reflector thickness reached a value of around 100 cm in the dry SiO_2 reflected system. These results indicate that a reflector thickness of about 20 to 30 cm is sufficient to estimate the criticality depending on the amount of H_2O in the reflector. However, in the dry SiO_2 reflected condition, a reflector thickness of at least 100 cm is necessary for the model to reach a maximum k_{eff}.

By comparing the H_2O and the wet SiO_2 moderated systems with the same wet SiO_2 reflector, R_{eff} was significantly higher in the wet SiO_2 moderator case than in the H_2O moderator case.

^{16}O scattering rates calculated by the participants were in good agreement with each other for the H_2O moderated systems. Both the scattering and capture rates of ^{28}Si were divided into two groups of higher and lower reaction rates. The discrepancy of ^{28}Si reaction rate data was caused by some participants using older nuclear data libraries, which contain only the natural silicon cross-section data instead of ^{28}Si.

As the reflector thickness increased, the ratio of neutron absorption rate to neutron production rate (A/P) in the whole system also increased. This behaviour is expected because the leaked neutrons are absorbed in the reflector with an increased reflector thickness. The increase in k_{eff} gives information regarding the combined effect of leakage and absorption, related to production. The geometric shape of the fissile material influences the effectiveness of the increased reflector thickness. A sphere of the fissile material will be less sensitive with an infinitely long fuel assembly than a large slab. It should also be noted that at least a 150-cm reflector thickness could be used if we use dry SiO_2 reflector in the criticality safety evaluation.

Generally, a good agreement was observed in the calculation results and the computer codes and libraries showed a sufficient level of diversity. The differences among the neutron multiplication factors and the reflector effects are moderate and consistent with the experience of the burn-up credit criticality safety benchmarks carried out by the NEA Expert Group on Burn-up Credit Criticality Safety (EGBUC). The results confirm the applicability of the modern criticality safety evaluation systems to the problems related to the direct disposal of used nuclear fuel.

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Appendix A. Calculation results of the participants[1]

1. All figures and tables in Appendix A were provided by the Japan Atomic Energy Agency (JAEA).

Table A.1 k_{eff} results of each participant for fresh fuel case (1/2)

Thickness [cm]	JAEA	GRS1	GRS2	GRS3	GRS4	VUJE	EDF1	EDF2	EDF3	EDF4	EDF5	EDF6	EMS1	EMS2	BFS	NCBJ1	NCBJ3	IRSN	EK	Ave.	SD	RSD (%)
H_2O mod.+ Dry SiO_2 ref																						
0	0.655	0.652	0.650	0.649	0.655	0.654	0.656	0.655	0.658	0.655	0.656	0.653	0.654	0.654	0.655	0.654	0.654	0.654	0.653	0.654	0.0020	0.31%
10	0.797	0.797	0.795	0.791	0.798	0.798	0.802	0.801	0.800	0.799	0.799	0.797	0.798	0.797	0.797	0.798	0.798	0.798	0.797	0.798	0.0021	0.27%
20	0.865	0.866	0.863	0.859	0.865	0.865	0.869	0.869	0.866	0.867	0.866	0.866	0.866	0.865	0.865	0.866	0.865	0.864	0.865	0.865	0.0021	0.24%
40	0.936	0.939	0.936	0.931	0.937	0.938	0.941	0.940	0.938	0.938	0.939	0.937	0.937	0.937	0.937	0.937	0.937	0.936	0.936	0.937	0.0019	0.21%
60	0.971	0.974	0.971	0.967	0.972	0.972	0.975	0.975	0.972	0.973	0.974	0.972	0.972	0.971	0.972	0.973	0.973	0.971	0.971	0.972	0.0018	0.19%
90	0.990	0.992	0.989	0.985	0.990	0.991	0.992	0.993	0.990	0.992	0.992	0.991	0.991	0.991	0.991	0.991	0.991	0.990	0.990	0.991	0.0017	0.17%
120	0.994	0.995	0.993	0.989	0.994	0.994	0.997	0.996	0.994	0.995	0.996	0.995	0.994	0.994	0.994	0.995	0.994	0.993	0.993	0.994	0.0017	0.17%
H_2O mod. + Wet SiO_2 ref																						
10	0.941	0.939	0.937	0.934	0.940	0.939	0.942	0.942	0.941	0.941	0.941	0.940	0.941	0.940	0.940	0.941	0.939	0.939	0.940	0.940	0.0019	0.21%
20	0.972	0.972	0.969	0.966	0.973	0.973	0.973	0.973	0.971	0.973	0.974	0.971	0.974	0.973	0.973	0.974	0.972	0.972	0.973	0.972	0.0018	0.19%
40	0.974	0.973	0.971	0.968	0.974	0.975	0.976	0.975	0.973	0.974	0.976	0.973	0.976	0.974	0.974	0.976	0.974	0.973	0.974	0.974	0.0019	0.20%
60	0.974	0.973	0.971	0.968	0.974	0.974	0.975	0.976	0.973	0.975	0.977	0.973	0.976	0.974	0.972	0.975	0.974	0.974	0.974	0.974	0.0019	0.19%

Table A.1 k_{eff} results of each participant for fresh fuel case (2/2)

Thickness [cm]	JAEA	GRS1	GRS2	GRS3	GRS4	VUJE	EDF1	EDF2	EDF3	EDF4	EDF5	EDF6	EMS1	EMS2	BFS	NCBJ1	NCBJ3	IRSN	EK	Ave.	SD	RSD (%)
H_2O mod. + H_2O ref.																						
10	0.925	0.922	0.920	0.917	0.925	0.925	0.924	0.924	0.925	0.924	0.926	0.922	0.926	0.925	0.925	0.925	0.925	0.924	0.924	0.924	0.0022	0.24%
20	0.927	0.925	0.923	0.920	0.928	0.927	0.927	0.927	0.928	0.927	0.929	0.925	0.929	0.928	0.928	0.928	0.928	0.926	0.927	0.927	0.0021	0.23%
40	0.927	0.925	0.923	0.920	0.928	0.928	0.926	0.927	0.927	0.927	0.929	0.925	0.929	0.928	0.928	0.928	0.928	0.926	0.926	0.927	0.0022	0.24%
Wet SiO_2 mod. + Wet SiO_2 ref.																						
0	0.311	0.309	0.304	0.303	0.307	0.307	0.309	0.309	0.305	0.306	0.306	0.305	0.306	0.307	0.307	0.306	0.307	0.304	0.304	0.307	0.0022	0.72%
10	0.693	0.689	0.684	0.680	0.686	0.686	0.688	0.688	0.683	0.686	0.686	0.684	0.686	0.686	0.686	0.686	0.686	0.684	0.685	0.686	0.0026	0.38%
20	0.744	0.742	0.738	0.734	0.740	0.741	0.740	0.740	0.734	0.739	0.740	0.737	0.740	0.741	0.740	0.741	0.740	0.738	0.738	0.739	0.0025	0.33%
40	0.746	0.745	0.740	0.737	0.743	0.743	0.743	0.742	0.737	0.741	0.743	0.741	0.743	0.743	0.744	0.744	0.743	0.739	0.741	0.742	0.0025	0.34%
60	0.746	0.745	0.740	0.737	0.743	0.743	0.743	0.743	0.737	0.741	0.743	0.740	0.743	0.744	0.743	0.742	0.743	0.740	0.741	0.742	0.0025	0.34%

Table A.2 k_{eff} results of each participant for used fuel case (30GWd/t, after 0 year)

Thickness [cm]	JAEA	GRS1	GRS2	GRS3	GRS4	VUJE	EDF1	EDF2	EDF3	EDF4	EDF5	EDF6	EMS1	EMS2	BFS	NCBJ1	NCBJ3	IRSN	EK	Ave.	SD	RSD (%)
H_2O mod.+ Dry SiO_2 ref.																						
0	0.541	0.540	0.540	0.540	0.540	0.540	0.540	0.540	0.541	0.541	0.540	0.542	0.541	0.540	0.540	0.546	0.540	0.540	0.539	0.541	0.0014	0.25%
10	0.658	0.657	0.657	0.657	0.657	0.657	0.659	0.659	0.658	0.658	0.659	0.660	0.659	0.657	0.657	0.665	0.657	0.658	0.656	0.658	0.0019	0.29%
40	0.772	0.772	0.772	0.772	0.772	0.772	0.773	0.773	0.770	0.772	0.772	0.774	0.772	0.771	0.772	0.781	0.771	0.771	0.770	0.772	0.0023	0.30%
120	0.820	0.819	0.819	0.819	0.819	0.819	0.820	0.819	0.818	0.820	0.821	0.821	0.821	0.819	0.819	0.829	0.819	0.820	0.817	0.820	0.0025	0.31%
H_2O mod. + Wet SiO_2 ref.																						
10	0.782	0.779	0.779	0.779	0.779	0.779	0.780	0.780	0.779	0.779	0.779	0.781	0.780	0.779	0.779	0.788	0.779	0.779	0.778	0.780	0.0022	0.28%
40	0.809	0.809	0.809	0.809	0.809	0.809	0.809	0.808	0.807	0.808	0.810	0.810	0.810	0.809	0.809	0.819	0.809	0.808	0.808	0.809	0.0024	0.30%
H_2O mod. + H_2O ref.																						
10	0.769	0.769	0.769	0.769	0.769	0.768	0.766	0.766	0.768	0.768	0.770	0.769	0.770	0.769	0.769	0.778	0.768	0.767	0.767	0.769	0.0024	0.31%
40	0.772	0.772	0.772	0.772	0.772	0.771	0.769	0.769	0.770	0.771	0.772	0.772	0.773	0.772	0.772	0.780	0.771	0.771	0.770	0.772	0.0023	0.30%

Table A.3 k_{eff} results of each participant for used fuel case (30GWd/t, after 30,000 years)

Thickness [cm]	JAEA	GRS1	GRS2	GRS3	GRS4	VUJE	EDF1	EDF2	EDF3	EDF4	EDF5	EDF6	EMS1	EMS2	BFS	NCBJ1	NCBJ3	IRSN	EK	Ave.	SD	RSD (%)
H_2O mod.+ Dry SiO_2 ref.																						
0	0.525	0.525	0.525	0.525	0.525	0.524	0.524	0.523	0.527	0.524	0.525	0.525	0.525	0.524	0.525	0.531	0.525	0.523	0.524	0.525	0.0017	0.33%
10	0.640	0.640	0.640	0.640	0.640	0.639	0.640	0.640	0.640	0.640	0.641	0.641	0.640	0.639	0.639	0.649	0.639	0.639	0.639	0.640	0.0021	0.33%
40	0.750	0.751	0.751	0.751	0.751	0.752	0.752	0.751	0.751	0.751	0.752	0.753	0.752	0.752	0.752	0.762	0.751	0.750	0.750	0.752	0.0026	0.35%
120	0.797	0.797	0.797	0.797	0.797	0.797	0.796	0.796	0.796	0.797	0.799	0.798	0.798	0.797	0.797	0.809	0.797	0.795	0.796	0.798	0.0030	0.37%
H_2O mod. + Wet SiO_2 ref.																						
10	0.760	0.759	0.759	0.759	0.759	0.759	0.758	0.758	0.758	0.758	0.760	0.760	0.759	0.759	0.759	0.770	0.758	0.758	0.758	0.759	0.0026	0.34%
40	0.787	0.787	0.787	0.787	0.787	0.788	0.785	0.786	0.786	0.786	0.788	0.787	0.788	0.787	0.787	0.798	0.787	0.786	0.786	0.787	0.0028	0.36%
H_2O mod. + H_2O ref.																						
10	0.748	0.749	0.749	0.749	0.749	0.749	0.746	0.745	0.748	0.747	0.750	0.748	0.749	0.749	0.748	0.759	0.748	0.747	0.747	0.748	0.0027	0.36%
40	0.750	0.751	0.751	0.751	0.751	0.751	0.747	0.747	0.750	0.749	0.752	0.750	0.752	0.751	0.751	0.761	0.751	0.749	0.750	0.751	0.0029	0.38%

Table A.4 k_{eff} results of each participant for used fuel case (30GWd/t, after 20 million years)

Thickness [cm]	JAEA	GRS1	GRS2	GRS3	GRS4	VUJE	EDF1	EDF2	EDF3	EDF4	EDF5	EDF6	EMS1	EMS2	BFS	NCBJ1	NCBJ3	IRSN	EK	Ave.	SD	RSD (%)
H_2O mod.+ Dry SiO_2 ref.																						
0	0.521	0.521	0.521	0.521	0.521	0.521	0.521	0.521	0.523	0.521	0.521	0.519	0.521	0.520	0.521	0.528	0.521	0.518	0.520	0.521	0.0019	0.36%
10	0.636	0.636	0.636	0.636	0.636	0.636	0.637	0.637	0.637	0.636	0.637	0.636	0.637	0.636	0.637	0.646	0.636	0.636	0.636	0.637	0.0023	0.36%
40	0.749	0.749	0.749	0.749	0.749	0.748	0.749	0.749	0.748	0.748	0.750	0.748	0.749	0.748	0.749	0.761	0.748	0.746	0.747	0.749	0.0029	0.39%
120	0.793	0.794	0.794	0.794	0.794	0.794	0.793	0.793	0.792	0.795	0.796	0.794	0.794	0.794	0.793	0.807	0.793	0.791	0.792	0.794	0.0033	0.41%
H_2O mod. + Wet SiO_2 ref.																						
10	0.759	0.757	0.757	0.757	0.757	0.756	0.757	0.756	0.757	0.757	0.758	0.756	0.758	0.756	0.757	0.769	0.757	0.755	0.756	0.757	0.0028	0.37%
40	0.784	0.785	0.785	0.785	0.785	0.785	0.783	0.783	0.782	0.784	0.786	0.784	0.786	0.784	0.785	0.797	0.785	0.783	0.784	0.785	0.0031	0.40%
H_2O mod. + H_2O ref.																						
10	0.747	0.746	0.746	0.746	0.746	0.746	0.744	0.744	0.746	0.745	0.747	0.744	0.748	0.746	0.747	0.758	0.747	0.746	0.745	0.747	0.0029	0.39%
40	0.748	0.749	0.749	0.749	0.749	0.749	0.747	0.746	0.748	0.748	0.750	0.746	0.750	0.749	0.749	0.760	0.749	0.746	0.748	0.749	0.0030	0.40%

Table A.5 k_{eff} results of each participant for used fuel case (45GWd/t, after 0 year)

Thickness [cm]	JAEA	GRS1	GRS2	GRS3	GRS4	VUJE	EDF1	EDF2	EDF3	EDF4	EDF5	EDF6	EMS1	EMS2	BFS	NCBJ1	NCBJ3	IRSN	EK	Ave.	SD	RSD (%)
H_2O *mod.+ Dry* SiO_2 *ref.*																						
0	0.492	0.492	0.492	0.492	0.492	0.493	0.492	0.492	0.493	0.492	0.493	0.493	0.492	0.492	0.492	0.499	0.491	0.491	0.491	0.492	0.0018	0.36%
10	0.599	0.598	0.598	0.598	0.598	0.598	0.600	0.600	0.598	0.599	0.599	0.601	0.600	0.598	0.598	0.608	0.598	0.598	0.597	0.599	0.0025	0.41%
40	0.703	0.702	0.702	0.702	0.702	0.703	0.703	0.703	0.701	0.702	0.703	0.704	0.703	0.702	0.702	0.714	0.701	0.701	0.700	0.703	0.0029	0.42%
120	0.746	0.745	0.745	0.745	0.745	0.747	0.746	0.746	0.744	0.747	0.746	0.748	0.747	0.745	0.745	0.759	0.745	0.744	0.743	0.746	0.0032	0.43%
H_2O *mod. + Wet* SiO_2 *ref.*																						
10	0.713	0.710	0.710	0.710	0.710	0.712	0.711	0.711	0.709	0.711	0.711	0.713	0.712	0.710	0.710	0.723	0.710	0.709	0.709	0.711	0.0030	0.42%
40	0.739	0.738	0.738	0.738	0.738	0.739	0.737	0.737	0.736	0.738	0.739	0.739	0.740	0.738	0.738	0.751	0.738	0.738	0.736	0.738	0.0031	0.42%
H_2O *mod. +* H_2O *ref.*																						
10	0.702	0.702	0.702	0.702	0.702	0.703	0.700	0.699	0.700	0.700	0.702	0.702	0.704	0.701	0.702	0.713	0.701	0.701	0.700	0.702	0.0030	0.42%
40	0.705	0.704	0.704	0.704	0.704	0.706	0.702	0.702	0.702	0.703	0.704	0.705	0.706	0.704	0.704	0.716	0.704	0.702	0.702	0.704	0.0030	0.43%

Table A.6 k_{eff} results of each participant for used fuel case (45GWd/t, after 30,000 years)

Thickness [cm]	JAEA	GRS1	GRS2	GRS3	GRS4	VUJE	EDF1	EDF2	EDF3	EDF4	EDF5	EDF6	EMS1	EMS2	BFS	NCBJ1	NCBJ3	IRSN	EK	Ave.	SD	RSD (%)
H_2O mod.+ Dry SiO_2 ref.																						
0	0.453	0.453	0.453	0.453	0.453	0.453	0.453	0.452	0.455	0.453	0.453	0.454	0.453	0.453	0.453	0.462	0.454	0.453	0.453	0.454	0.0020	0.44%
10	0.553	0.553	0.553	0.553	0.553	0.552	0.552	0.553	0.553	0.553	0.553	0.555	0.553	0.552	0.552	0.564	0.553	0.551	0.552	0.553	0.0027	0.48%
40	0.648	0.649	0.649	0.649	0.649	0.648	0.648	0.648	0.649	0.648	0.650	0.650	0.649	0.649	0.649	0.663	0.649	0.647	0.647	0.649	0.0033	0.51%
120	0.688	0.688	0.688	0.688	0.688	0.688	0.687	0.686	0.688	0.688	0.690	0.690	0.689	0.688	0.688	0.703	0.688	0.687	0.687	0.689	0.0036	0.52%
H_2O mod. + Wet SiO_2 ref.																						
10	0.658	0.657	0.657	0.657	0.657	0.657	0.656	0.656	0.657	0.656	0.658	0.658	0.657	0.656	0.657	0.670	0.657	0.657	0.656	0.658	0.0032	0.49%
40	0.680	0.682	0.682	0.682	0.682	0.681	0.679	0.679	0.680	0.680	0.682	0.682	0.682	0.681	0.681	0.696	0.682	0.681	0.681	0.682	0.0035	0.51%
H_2O mod. + H_2O ref.																						
10	0.642	0.649	0.649	0.649	0.649	0.649	0.645	0.645	0.648	0.647	0.649	0.648	0.650	0.648	0.648	0.661	0.649	0.647	0.648	0.648	0.0037	0.57%
40	0.644	0.651	0.651	0.651	0.651	0.651	0.647	0.647	0.650	0.649	0.651	0.651	0.652	0.650	0.651	0.663	0.651	0.649	0.650	0.650	0.0037	0.57%

Table A.7 k_{eff} results of each participant for used fuel case (45GWd/t, after 20 million years)

Thickness [cm]	JAEA	GRS1	GRS2	GRS3	GRS4	VUJE	EDF1	EDF2	EDF3	EDF4	EDF5	EDF6	EMS1	EMS2	BFS	NCBJ1	NCBJ3	IRSN	EK	Ave.	SD	RSD (%)
H_2O mod.+ Dry SiO_2 ref.																						
0	0.446	0.446	0.446	0.446	0.446	0.446	0.445	0.445	0.446	0.445	0.446	0.445	0.445	0.445	0.446	0.455	0.445	0.445	0.445	0.446	0.0022	0.49%
10	0.545	0.544	0.544	0.544	0.544	0.544	0.545	0.545	0.544	0.545	0.545	0.544	0.545	0.544	0.544	0.557	0.544	0.545	0.544	0.545	0.0029	0.54%
40	0.641	0.640	0.640	0.640	0.640	0.640	0.640	0.641	0.639	0.640	0.641	0.640	0.641	0.640	0.640	0.656	0.640	0.639	0.639	0.641	0.0036	0.56%
120	0.679	0.678	0.678	0.678	0.678	0.679	0.678	0.678	0.677	0.679	0.680	0.679	0.679	0.678	0.678	0.695	0.678	0.676	0.677	0.679	0.0040	0.59%
H_2O mod. + Wet SiO_2 ref.																						
10	0.651	0.649	0.649	0.649	0.649	0.649	0.649	0.649	0.649	0.650	0.651	0.649	0.650	0.649	0.650	0.665	0.649	0.646	0.649	0.650	0.0037	0.56%
40	0.674	0.673	0.673	0.673	0.673	0.673	0.672	0.672	0.671	0.672	0.675	0.672	0.674	0.673	0.673	0.689	0.673	0.672	0.672	0.674	0.0038	0.57%
H_2O mod. + H_2O ref.																						
10	0.648	0.641	0.641	0.641	0.641	0.641	0.639	0.639	0.641	0.640	0.642	0.639	0.643	0.641	0.641	0.656	0.641	0.640	0.641	0.642	0.0039	0.61%
40	0.650	0.643	0.643	0.643	0.643	0.644	0.641	0.641	0.642	0.641	0.644	0.641	0.644	0.643	0.643	0.658	0.644	0.641	0.642	0.644	0.0040	0.63%

Table A.8 Difference of k_{eff} of each participant from the average over all participants for fresh fuel case (1/2)

Thickness [cm]	JAEA	GRS1	GRS2	GRS3	GRS4	VUJE	EDF1	EDF2	EDF3	EDF4	EDF5	EDF6	EMS1	EMS2	BFS	NCBJ1	NCBJ3	IRSN	EK	Ave.
H_2O mod.+ Dry SiO_2 ref.																				
0	0.001	-0.002	-0.004	-0.005	0.001	0.001	0.002	0.001	0.004	0.001	0.002	-0.001	0.000	0.001	0.001	0.000	0.000	0.000	0.000	0.000
10	-0.001	-0.001	-0.003	-0.006	0.000	0.000	0.004	0.003	0.002	0.001	0.001	0.000	0.000	-0.001	0.000	0.000	0.000	0.000	0.000	0.000
20	0.000	0.001	-0.002	-0.006	0.000	0.000	0.004	0.004	0.001	0.001	0.001	0.000	0.000	0.000	0.000	0.000	-0.001	-0.001	-0.001	0.000
40	-0.001	0.002	-0.002	-0.006	0.000	0.000	0.004	0.003	0.000	0.001	0.001	0.000	0.000	0.000	0.000	0.000	0.000	-0.001	-0.001	0.000
60	-0.001	0.002	-0.001	-0.005	0.000	0.000	0.003	0.003	0.000	0.001	0.002	0.000	0.000	-0.001	0.000	0.001	0.001	-0.001	-0.001	0.000
90	-0.001	0.001	-0.002	-0.005	0.000	0.000	0.002	0.002	-0.001	0.002	0.002	0.001	0.000	0.000	0.000	0.001	0.000	-0.001	-0.001	0.000
120	0.000	0.001	-0.002	-0.005	0.000	0.000	0.002	0.002	0.000	0.001	0.002	0.000	0.000	0.000	0.000	0.001	0.000	-0.001	-0.001	0.000
H_2O mod.+ Wet SiO_2 ref.																				
10	0.002	-0.001	-0.003	-0.006	0.000	0.000	0.002	0.002	0.001	0.002	0.001	0.000	0.001	0.000	0.000	0.001	0.000	-0.001	0.000	0.000
20	0.000	0.000	-0.003	-0.006	0.000	0.001	0.001	0.001	-0.001	0.001	0.002	-0.001	0.002	0.001	0.001	0.002	0.000	0.000	0.001	0.000
40	0.000	-0.001	-0.003	-0.006	0.001	0.001	0.002	0.001	-0.001	0.000	0.002	-0.001	0.002	0.000	0.000	0.002	0.001	0.000	0.000	0.000
60	0.000	0.000	-0.003	-0.006	0.001	0.000	0.001	0.002	-0.001	0.001	0.003	-0.001	0.002	0.000	-0.002	0.001	0.000	0.001	0.000	0.000

Table A.8 Difference of k_{eff} of each participant from the average over all participants for fresh fuel case (2/2)

Thickness [cm]	JAEA	GRS1	GRS2	GRS3	GRS4	VUJE	EDF1	EDF2	EDF3	EDF4	EDF5	EDF6	EMS1	EMS2	BFS	NCBJ1	NCBJ3	IRSN	EK	Ave.
H_2O mod.+ Dry SiO_2 ref.																				
10	0.001	-0.002	-0.004	-0.007	0.001	0.001	0.000	0.000	0.001	0.001	0.003	-0.002	0.002	0.001	0.001	0.001	0.001	0.000	0.000	0.000
20	0.000	-0.001	-0.004	-0.007	0.001	0.000	0.000	0.000	0.001	0.000	0.003	-0.002	0.002	0.001	0.001	0.002	0.001	0.000	0.000	0.000
40	0.000	-0.001	-0.004	-0.007	0.001	0.001	0.000	0.000	0.001	0.001	0.002	-0.002	0.002	0.001	0.001	0.002	0.001	0.000	0.000	0.000
Wet SiO_2 mod. + Wet SiO_2 ref.																				
0	0.005	0.003	-0.002	-0.004	0.001	0.001	0.003	0.003	-0.001	0.000	0.000	-0.001	0.000	0.000	0.001	-0.001	0.001	-0.003	-0.003	0.000
10	0.007	0.003	-0.002	-0.006	0.000	0.000	0.002	0.002	-0.003	0.000	0.000	-0.002	0.000	0.000	0.000	0.000	0.001	-0.002	-0.001	0.000
20	0.004	0.003	-0.002	-0.005	0.001	0.002	0.001	0.001	-0.005	-0.001	0.001	-0.002	0.001	0.001	0.001	0.001	0.001	-0.001	-0.002	0.000
40	0.004	0.003	-0.002	-0.005	0.001	0.001	0.001	0.000	-0.005	-0.001	0.001	-0.001	0.001	0.001	0.002	0.002	0.001	-0.003	-0.001	0.000
60	0.004	0.003	-0.002	-0.005	0.001	0.001	0.001	0.001	-0.005	-0.001	0.001	-0.002	0.001	0.002	0.001	0.000	0.001	-0.002	-0.001	0.000

Table A.9 Difference of k_{eff} of each participant from the average over all participants for used fuel case (30GWd/t, after 0 year)

Thickness [cm]	JAEA	GRS1	GRS2	GRS3	GRS4	VUJE	EDF1	EDF2	EDF3	EDF4	EDF5	EDF6	EMS1	EMS2	BFS	NCBJ1	NCBJ3	IRSN	EK	Ave.
H_2O mod.+ Dry SiO_2 ref.																				
0	0.000	0.000	0.000	0.000	0.000	0.000	0.000	-0.001	0.000	0.000	-0.001	0.001	0.000	-0.001	-0.001	0.005	-0.001	-0.001	-0.002	0.000
10	0.000	-0.001	-0.001	-0.001	-0.001	-0.002	0.000	0.000	-0.001	-0.001	0.000	0.002	0.000	-0.001	-0.001	0.007	-0.001	0.000	-0.002	0.000
40	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	0.001	0.000	-0.002	0.000	0.000	0.001	0.000	-0.001	-0.001	0.008	-0.001	-0.002	-0.003	0.000
120	0.000	-0.001	-0.001	-0.001	-0.001	-0.001	0.000	-0.001	-0.003	0.000	0.001	0.001	0.000	-0.001	-0.001	0.009	-0.001	0.000	-0.003	0.000
H_2O mod. + Wet SiO_2 ref.																				
10	0.003	0.000	0.000	0.000	0.000	0.000	0.001	0.001	0.000	0.000	0.001	0.002	0.001	0.000	0.000	0.009	0.000	0.000	-0.001	0.001
40	0.001	0.000	0.000	0.000	0.000	0.001	0.000	-0.001	-0.002	0.000	0.002	0.001	0.002	0.000	0.001	0.010	0.000	0.000	-0.001	0.001
H_2O mod. + H_2O ref.																				
10	0.000	0.000	0.000	0.000	0.000	-0.001	-0.003	-0.003	-0.001	-0.001	0.000	-0.001	0.001	0.000	-0.001	0.008	-0.001	-0.002	-0.002	0.000
40	0.000	0.000	0.000	0.000	0.000	0.000	-0.002	-0.002	-0.001	0.000	0.001	0.001	0.002	0.001	0.001	0.009	0.000	0.000	-0.001	0.001

Table A.10 Difference of k_{eff} of each participant from the average over all participants for used fuel case (30GWd/t, after 30,000 years)

Thickness [cm]	JAEA	GRS1	GRS2	GRS3	GRS4	VUJE	EDF1	EDF2	EDF3	EDF4	EDF5	EDF6	EMS1	EMS2	BFS	NCBJ1	NCBJ3	IRSN	EK	Ave.
H_2O mod.+ Dry SiO_2 ref.																				
0	0.000	0.000	0.000	0.000	0.000	-0.001	-0.001	-0.002	0.001	-0.001	0.000	-0.001	0.000	-0.001	0.000	0.006	-0.001	-0.003	-0.001	0.000
10	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	0.000	0.000	0.000	-0.001	0.000	0.000	0.000	-0.001	-0.001	0.008	-0.001	-0.002	-0.001	0.000
40	-0.002	-0.001	-0.001	-0.001	-0.001	0.000	-0.001	-0.001	-0.001	-0.001	0.000	0.000	0.000	-0.001	-0.001	0.010	-0.001	-0.002	-0.002	0.000
120	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.002	-0.002	-0.002	-0.001	0.001	0.000	0.000	-0.001	-0.001	0.011	-0.001	-0.003	-0.002	0.000
H_2O mod. + Wet SiO_2 ref.																				
10	0.000	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.002	-0.001	-0.002	0.001	0.000	0.000	0.000	-0.001	0.010	-0.001	-0.002	-0.002	0.000
40	-0.001	0.000	0.000	0.000	0.000	0.000	-0.002	-0.001	-0.002	-0.002	0.001	0.000	0.001	0.000	0.000	0.011	0.000	-0.001	-0.001	0.000
H_2O mod. + H_2O ref.																				
10	-0.001	0.000	0.000	0.000	0.000	0.000	-0.003	-0.004	-0.001	-0.002	0.001	-0.001	0.000	0.000	-0.001	0.010	-0.001	-0.002	-0.002	0.000
40	-0.001	0.000	0.000	0.000	0.000	0.000	-0.004	-0.004	-0.002	-0.003	0.001	-0.002	0.001	0.000	0.000	0.010	-0.001	-0.002	-0.001	-0.001

Table A.11 Difference of k_{eff} of each participant from the average over all participants for used fuel case (30GWd/t, after 20 million years)

Thickness [cm]	JAEA	GRS1	GRS2	GRS3	GRS4	VUJE	EDF1	EDF2	EDF3	EDF4	EDF5	EDF6	EMS1	EMS2	BFS	NCBJ1	NCBJ3	IRSN	EK	Ave.
H_2O mod.+ Dry SiO_2 ref.																				
0	0.000	0.000	0.000	0.000	0.000	-0.001	-0.001	-0.001	0.001	-0.001	0.000	-0.003	-0.001	-0.001	0.000	0.006	-0.001	-0.003	-0.002	0.000
10	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	0.000	0.000	0.000	-0.001	0.000	-0.002	0.000	-0.001	-0.001	0.009	-0.001	-0.001	-0.002	0.000
40	0.000	-0.001	-0.001	-0.001	-0.001	-0.001	0.000	0.000	-0.002	-0.001	0.001	-0.001	-0.001	-0.002	-0.001	0.011	-0.001	-0.003	-0.002	0.000
120	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.002	0.000	0.001	-0.001	0.000	-0.001	-0.001	0.012	-0.001	-0.004	-0.002	0.000
H_2O mod. + Wet SiO_2 ref.																				
10	0.002	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	-0.001	0.001	-0.001	0.000	0.012	0.000	-0.001	-0.001	0.001
40	0.000	0.001	0.001	0.001	0.001	0.001	-0.001	-0.001	-0.002	-0.001	0.002	-0.001	0.001	0.000	0.000	0.013	0.000	-0.002	-0.001	0.001
H_2O mod. + H_2O ref.																				
10	0.000	-0.001	-0.001	-0.001	-0.001	-0.001	-0.003	-0.004	-0.001	-0.002	0.000	-0.003	0.001	-0.001	-0.001	0.011	0.000	-0.001	-0.002	-0.001
40	-0.001	0.000	0.000	0.000	0.000	-0.001	-0.003	-0.003	-0.001	-0.002	0.000	-0.004	0.001	-0.001	-0.001	0.011	0.000	-0.003	-0.001	-0.001

Table A.12 Difference of k_{eff} of each participant from the average over all participants for used fuel case (45GWd/t, after 0 year)

Thickness [cm]	JAEA	GRS1	GRS2	GRS3	GRS4	VUJE	EDF1	EDF2	EDF3	EDF4	EDF5	EDF6	EMS1	EMS2	BFS	NCBJ1	NCBJ3	IRSN	EK	Ave.
H_2O mod.+ Dry SiO_2 ref.																				
0	0.000	-0.001	-0.001	-0.001	-0.001	0.001	-0.001	-0.001	0.000	-0.001	0.000	0.000	0.000	-0.001	-0.001	0.006	-0.001	-0.002	-0.002	0.000
10	0.000	-0.001	-0.001	-0.001	-0.001	-0.001	0.001	0.000	-0.001	0.000	-0.001	0.002	0.000	-0.002	-0.002	0.009	-0.001	-0.001	-0.003	0.000
40	0.000	-0.001	-0.001	-0.001	-0.001	0.000	0.000	0.000	-0.002	-0.001	0.000	0.001	0.000	-0.002	-0.001	0.011	-0.002	-0.002	-0.003	0.000
120	0.000	-0.001	-0.001	-0.001	-0.001	0.000	-0.001	-0.001	-0.003	0.000	0.000	0.001	0.000	-0.002	-0.001	0.012	-0.002	-0.003	-0.003	0.000
H_2O mod. + Wet SiO_2 ref.																				
10	0.002	-0.001	-0.001	-0.001	-0.001	0.001	0.000	-0.001	-0.002	-0.001	-0.001	0.001	0.001	-0.001	-0.002	0.011	-0.002	-0.002	-0.002	0.000
40	0.000	-0.001	-0.001	-0.001	-0.001	0.000	-0.001	-0.002	-0.002	0.000	0.000	0.001	0.002	-0.001	-0.001	0.012	-0.001	-0.001	-0.002	0.000
H_2O mod. + H_2O ref.																				
10	0.000	-0.001	-0.001	-0.001	-0.001	0.001	-0.002	-0.004	-0.002	-0.002	0.000	0.000	0.001	-0.001	-0.001	0.011	-0.001	-0.001	-0.002	-0.001
40	0.000	-0.001	-0.001	-0.001	-0.001	0.001	-0.003	-0.003	-0.003	-0.002	0.000	0.000	0.001	-0.001	-0.001	0.011	-0.001	-0.003	-0.002	-0.001

Table A.13 Difference of k_{eff} of each participant from the average over all participants for used fuel case (45GWd/t, after 30,000 years)

Thickness [cm]	JAEA	GRS1	GRS2	GRS3	GRS4	VUJE	EDF1	EDF2	EDF3	EDF4	EDF5	EDF6	EMS1	EMS2	BFS	NCBJ1	NCBJ3	IRSN	EK	Ave.
H_2O mod.+ Dry SiO_2 ref.																				
0	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.002	-0.002	0.000	-0.001	-0.001	0.000	-0.001	-0.001	-0.001	0.008	0.000	-0.001	-0.001	0.000
10	-0.001	-0.001	-0.001	-0.001	-0.001	-0.002	-0.002	-0.001	-0.001	-0.001	0.000	0.001	0.000	-0.002	-0.001	0.010	-0.001	-0.002	-0.002	0.000
40	-0.002	-0.001	-0.001	-0.001	-0.001	-0.002	-0.002	-0.002	-0.001	-0.002	0.000	0.000	-0.001	-0.001	-0.001	0.013	-0.001	-0.003	-0.002	-0.001
120	-0.002	-0.001	-0.001	-0.001	-0.001	-0.001	-0.003	-0.003	-0.002	-0.001	0.000	0.000	-0.001	-0.002	-0.001	0.014	-0.001	-0.002	-0.002	-0.001
H_2O mod. + Wet SiO_2 ref.																				
10	0.000	-0.001	-0.001	-0.001	-0.001	-0.001	-0.002	-0.002	-0.001	-0.002	0.000	0.000	-0.001	-0.001	-0.001	0.012	-0.001	-0.001	-0.002	0.000
40	-0.001	0.000	0.000	0.000	0.000	0.000	-0.002	-0.003	-0.002	-0.002	0.000	0.000	0.000	0.000	-0.001	0.014	0.000	-0.001	-0.001	0.000
H_2O mod. + H_2O ref.																				
10	-0.007	-0.001	-0.001	-0.001	-0.001	0.000	-0.004	-0.004	-0.001	-0.002	0.000	-0.001	0.001	-0.001	-0.001	0.012	0.000	-0.002	-0.001	-0.001
40	-0.007	0.000	0.000	0.000	0.000	0.000	-0.004	-0.004	-0.001	-0.003	0.000	0.000	0.001	-0.001	0.000	0.012	-0.001	-0.002	-0.002	-0.001

Table A.14 Difference of k_{eff} of each participant from the average over all participants for used fuel case (45GWd/t, after 20 million years)

Thickness [cm]	JAEA	GRS1	GRS2	GRS3	GRS4	VUJE	EDF1	EDF2	EDF3	EDF4	EDF5	EDF6	EMS1	EMS2	BFS	NCBJ1	NCBJ3	IRSN	EK	Ave.
H_2O mod.+ Dry SiO_2 ref.																				
0	0.000	-0.001	-0.001	-0.001	-0.001	0.000	-0.002	-0.001	0.000	-0.001	-0.001	-0.002	-0.001	-0.001	-0.001	0.008	-0.001	-0.001	-0.002	0.000
10	-0.001	-0.001	-0.001	-0.001	-0.001	-0.002	0.000	0.000	-0.001	-0.001	0.000	-0.002	-0.001	-0.002	-0.002	0.011	-0.001	-0.001	-0.002	-0.001
40	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.003	-0.002	-0.001	-0.001	-0.001	-0.001	-0.002	0.014	-0.002	-0.003	-0.003	-0.001
120	0.000	-0.001	-0.001	-0.001	-0.001	-0.001	-0.002	-0.002	-0.003	-0.001	0.000	-0.001	0.000	-0.002	-0.002	0.015	-0.001	-0.003	-0.003	-0.001
H_2O mod. + Wet SiO_2 ref.																				
10	0.001	-0.001	-0.001	-0.001	-0.001	-0.001	-0.002	-0.001	-0.001	-0.001	0.000	-0.002	0.000	-0.002	-0.001	0.014	-0.002	-0.004	-0.002	0.000
40	0.000	-0.001	-0.001	-0.001	-0.001	-0.001	-0.002	-0.002	-0.003	-0.002	0.001	-0.002	0.000	-0.001	-0.001	0.015	-0.001	-0.002	-0.002	0.000
H_2O mod. + H_2O ref.																				
10	0.006	-0.001	-0.001	-0.001	-0.001	-0.001	-0.004	-0.004	-0.002	-0.002	-0.001	-0.004	0.000	-0.002	-0.002	0.013	-0.002	-0.003	-0.002	-0.001
40	0.006	-0.001	-0.001	-0.001	-0.001	-0.001	-0.004	-0.004	-0.002	-0.003	-0.001	-0.004	0.000	-0.001	-0.001	0.014	-0.001	-0.004	-0.002	-0.001

Table A.15 Reflector effect factor results of each participant for fresh fuel case (1/2)

Thickness [cm]	JAEA	GRS1	GRS2	GRS3	GRS4	VUJE	EDF1	EDF2	EDF3	EDF4	EDF5	EDF6	EMS1	EMS2	BFS	NCBJ1	NCBJ3	IRSN	EK	Ave.	SD	RSD (%)
H_2O mod.+ Dry SiO_2 ref.																						
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000	0.00%
10	21.78	22.18	22.30	22.00	21.83	21.87	22.24	22.32	21.59	21.94	21.89	22.17	22.00	21.80	21.78	22.03	21.88	22.01	22.05	21.98	0.196	0.89%
20	32.16	32.80	32.83	32.45	32.17	32.25	32.59	32.68	31.72	32.32	32.16	32.62	32.33	32.23	32.15	32.39	32.17	32.17	32.35	32.34	0.271	0.84%
40	43.07	43.97	43.96	43.57	43.15	43.25	43.53	43.55	42.56	43.14	43.19	43.53	43.29	43.16	43.09	43.38	43.17	43.25	43.30	43.32	0.323	0.75%
60	48.40	49.30	49.35	49.00	48.49	48.51	48.74	48.83	47.76	48.51	48.56	48.91	48.63	48.44	48.46	48.78	48.63	48.53	48.61	48.65	0.348	0.71%
90	51.17	52.08	52.17	51.87	51.30	51.38	51.33	51.57	50.51	51.47	51.40	51.92	51.50	51.39	51.32	51.64	51.44	51.40	51.47	51.49	0.362	0.70%
120	51.82	52.63	52.71	52.44	51.87	51.90	51.97	52.11	51.12	51.89	51.95	52.41	51.97	51.93	51.87	52.21	51.94	51.90	52.01	52.03	0.349	0.67%
H_2O mod. + Wet SiO_2 ref.																						
10	43.80	43.97	44.13	43.90	43.57	43.53	43.62	43.81	43.04	43.69	43.57	43.99	43.82	43.63	43.56	43.86	43.55	43.63	43.86	43.71	0.238	0.54%
20	48.49	49.00	49.15	48.91	48.57	48.65	48.39	48.54	47.70	48.50	48.59	48.85	48.94	48.64	48.56	48.94	48.56	48.67	48.87	48.66	0.312	0.64%
40	48.82	49.27	49.42	49.19	48.86	48.91	48.79	48.85	47.88	48.74	48.95	49.05	49.17	48.83	48.82	49.23	48.92	48.93	49.12	48.93	0.318	0.65%
60	48.83	49.29	49.43	49.21	48.86	48.85	48.68	48.98	47.99	48.79	48.97	49.10	49.16	48.86	48.46	49.10	48.89	49.07	49.09	48.93	0.319	0.65%

Table A.15 Reflector effect factor results of each participant for fresh fuel case (2/2)

Thickness [cm]	JAEA	GRS1	GRS2	GRS3	GRS4	VUJE	EDF1	EDF2	EDF3	EDF4	EDF5	EDF6	EMS1	EMS2	BFS	NCBJ1	NCBJ3	IRSN	EK	Ave.	SD	RSD (%)
H_2O mod. + H_2O ref.																						
10	41.28	41.42	41.52	41.39	41.28	41.29	40.92	41.07	40.64	41.11	41.33	41.30	41.51	41.35	41.24	41.53	41.32	41.36	41.37	41.27	0.216	0.52%
20	41.63	41.88	41.98	41.85	41.74	41.66	41.38	41.49	41.07	41.54	41.77	41.74	41.97	41.74	41.75	42.01	41.77	41.70	41.86	41.71	0.227	0.54%
40	41.63	41.90	41.98	41.84	41.75	41.78	41.27	41.49	40.99	41.55	41.71	41.68	42.06	41.77	41.71	42.00	41.80	41.71	41.80	41.71	0.253	0.61%
Wet SiO_2 mod. + Wet SiO_2 ref.																						
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000	0.00%
10	122.57	122.84	124.73	124.62	123.31	123.26	122.43	122.65	123.89	124.12	123.89	124.33	124.00	123.63	123.45	124.35	123.24	125.50	125.23	123.79	0.877	0.71%
20	138.70	140.19	142.37	142.31	140.93	141.09	139.17	139.34	140.56	141.37	141.55	141.67	141.87	141.33	141.02	142.25	140.71	143.08	142.68	141.17	1.198	0.85%
40	139.57	141.15	143.29	143.23	141.91	141.96	140.01	140.12	141.51	142.09	142.53	142.79	142.77	142.27	142.10	143.22	141.72	143.46	143.80	142.08	1.201	0.85%
60	139.61	141.16	143.30	143.28	141.95	141.88	140.08	140.34	141.45	142.12	142.43	142.52	142.83	142.30	141.96	142.81	141.76	143.74	143.70	142.06	1.162	0.82%

Table A.16 Reflector effect factor results of each participant for used fuel case (30GWd/t, after 0 year)

Thickness [cm]	JAEA	GRS1	GRS2	GRS3	GRS4	VUJE	EDF1	EDF2	EDF3	EDF4	EDF5	EDF6	EMS1	EMS2	BFS	NCBJ1	NCBJ3	IRSN	EK	Ave.	SD	RSD (%)
H_2O *mod.+ Dry* SiO_2 *ref.*																						
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000	0.00%
10	21.66	21.64	21.64	21.64	21.64	21.57	21.91	22.04	21.57	21.68	21.96	21.88	21.75	21.81	21.68	21.91	21.67	21.94	21.84	21.76	0.146	0.67%
40	42.73	42.78	42.78	42.78	42.78	42.82	43.06	43.14	42.32	42.89	42.96	42.82	42.77	42.95	42.82	43.15	42.85	42.78	42.92	42.85	0.178	0.42%
120	51.68	51.59	51.59	51.59	51.59	51.58	51.72	51.71	51.10	51.69	52.00	51.62	51.71	51.82	51.66	52.05	51.61	51.89	51.68	51.68	0.197	0.38%
H_2O *mod. + Wet* SiO_2 *ref.*																						
10	44.51	44.14	44.14	44.14	44.14	44.21	44.25	44.42	43.87	44.16	44.33	44.15	44.24	44.37	44.24	44.47	44.21	44.33	44.41	44.25	0.151	0.34%
40	49.67	49.69	49.69	49.69	49.69	49.79	49.63	49.68	49.07	49.55	50.04	49.56	49.83	49.89	49.80	50.08	49.74	49.71	49.97	49.73	0.217	0.44%
H_2O *mod. +* H_2O *ref.*																						
10	42.23	42.26	42.26	42.26	42.26	42.18	41.82	41.92	41.88	42.11	42.50	41.91	42.38	42.54	42.28	42.53	42.29	42.04	42.41	42.21	0.219	0.52%
40	42.66	42.77	42.77	42.77	42.77	42.77	42.38	42.40	42.28	42.57	42.94	42.52	42.94	43.00	42.84	43.02	42.81	42.84	42.91	42.74	0.214	0.50%

Table A.17 Reflector effect factor results of each participant for used fuel case (30GWd/t, after 30,000 years)

Thickness [cm]	JAEA	GRS1	GRS2	GRS3	GRS4	VUJE	EDF1	EDF2	EDF3	EDF4	EDF5	EDF6	EMS1	EMS2	BFS	NCBJ1	NCBJ3	IRSN	EK	Ave.	SD	RSD (%)
H_2O mod.+ Dry SiO_2 ref.																						
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000	0.00%
10	21.87	21.85	21.85	21.85	21.85	21.87	22.28	22.34	21.59	22.05	21.95	22.15	22.04	21.99	21.85	22.12	21.84	22.19	22.00	21.98	0.182	0.83%
40	42.98	43.18	43.18	43.18	43.18	43.40	43.50	43.57	42.61	43.25	43.16	43.46	43.37	43.44	43.26	43.56	43.22	43.51	43.18	43.27	0.229	0.53%
120	51.81	51.90	51.90	51.90	51.90	52.07	52.00	52.04	51.22	52.00	52.07	52.17	52.00	52.07	51.94	52.39	51.92	52.20	51.88	51.97	0.228	0.44%
H_2O mod. + Wet SiO_2 ref.																						
10	44.73	44.56	44.56	44.56	44.56	44.65	44.80	44.83	44.02	44.56	44.76	44.82	44.71	44.87	44.58	44.91	44.58	44.99	44.68	44.67	0.208	0.47%
40	49.90	49.99	49.99	49.99	49.99	50.20	49.95	50.16	49.20	49.89	50.07	50.06	50.25	50.16	49.96	50.33	50.03	50.39	50.05	50.03	0.244	0.49%
H_2O mod. + H_2O ref.																						
10	42.60	42.62	42.62	42.62	42.62	42.80	42.35	42.44	42.04	42.50	42.70	42.53	42.75	42.88	42.63	42.82	42.68	42.88	42.66	42.62	0.197	0.46%
40	42.91	43.11	43.11	43.11	43.11	43.24	42.68	42.81	42.33	42.79	43.19	42.89	43.28	43.32	43.17	43.31	43.10	43.39	43.16	43.05	0.263	0.61%

Table A.18 Reflector effect factor results of each participant for used fuel case (30GWd/t, after 20 million years)

Thickness [cm]	JAEA	GRS1	GRS2	GRS3	GRS4	VUJE	EDF1	EDF2	EDF3	EDF4	EDF5	EDF6	EMS1	EMS2	BFS	NCBJ1	NCBJ3	IRSN	EK	Ave.	SD	RSD (%)
H_2O mod.+ Dry SiO_2 ref.																						
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000	0.00%
10	22.07	22.13	22.13	22.13	22.13	22.17	22.44	22.38	21.89	22.27	22.23	22.55	22.35	22.25	22.16	22.47	22.19	22.70	22.31	22.26	0.189	0.85%
40	43.67	43.68	43.68	43.68	43.68	43.68	43.91	43.90	43.11	43.78	43.87	44.20	43.81	43.72	43.70	44.13	43.67	43.92	43.72	43.76	0.222	0.51%
120	52.17	52.34	52.34	52.34	52.34	52.36	52.40	52.43	51.63	52.64	52.62	53.03	52.58	52.49	52.29	52.92	52.33	52.53	52.40	52.43	0.288	0.55%
H_2O mod. + Wet SiO_2 ref.																						
10	45.53	45.24	45.24	45.24	45.24	45.23	45.35	45.32	44.76	45.42	45.31	45.70	45.58	45.30	45.24	45.64	45.35	45.72	45.46	45.36	0.221	0.49%
40	50.44	50.65	50.65	50.65	50.65	50.74	50.44	50.45	49.71	50.53	50.80	51.02	50.90	50.70	50.60	51.07	50.68	50.94	50.77	50.65	0.291	0.58%
H_2O mod. + H_2O ref.																						
10	43.24	43.27	43.27	43.27	43.27	43.24	42.91	42.84	42.67	43.21	43.28	43.37	43.66	43.39	43.28	43.55	43.36	43.85	43.36	43.28	0.267	0.62%
40	43.55	43.77	43.77	43.77	43.77	43.76	43.43	43.36	43.13	43.61	43.85	43.75	44.07	43.88	43.68	44.06	43.83	43.90	43.91	43.73	0.232	0.53%

Table A.19 Reflector effect factor results of each participant for used fuel case (45GWd/t, after 0 year)

Thickness [cm]	JAEA	GRS1	GRS2	GRS3	GRS4	VUJE	EDF1	EDF2	EDF3	EDF4	EDF5	EDF6	EMS1	EMS2	BFS	NCBJ1	NCBJ3	IRSN	EK	Ave.	SD	RSD (%)
H_2O mod.+ Dry SiO_2 ref.																						
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000	0.00%
10	21.64	21.61	21.61	21.61	21.61	21.26	21.99	21.98	21.45	21.79	21.54	21.91	21.87	21.55	21.62	21.89	21.71	21.92	21.58	21.69	0.195	0.90%
40	42.76	42.76	42.76	42.76	42.76	42.45	42.97	42.91	42.24	42.64	42.67	42.86	42.79	42.70	42.75	43.11	42.74	42.90	42.68	42.75	0.185	0.43%
120	51.55	51.53	51.53	51.53	51.53	51.38	51.54	51.70	51.00	51.75	51.52	51.62	51.75	51.49	51.61	52.00	51.62	51.47	51.53	51.56	0.191	0.37%
H_2O mod. + Wet SiO_2 ref.																						
10	44.87	44.42	44.42	44.42	44.42	44.32	44.57	44.54	43.96	44.43	44.30	44.54	44.73	44.47	44.42	44.78	44.44	44.49	44.51	44.48	0.193	0.43%
40	49.97	50.01	50.01	50.01	50.01	49.71	49.80	49.79	49.34	49.96	49.94	49.88	50.37	50.02	50.02	50.40	50.13	50.28	50.05	49.98	0.238	0.48%
H_2O mod. + H_2O ref.																						
10	42.58	42.67	42.67	42.67	42.67	42.51	42.28	42.12	42.09	42.28	42.51	42.47	42.93	42.64	42.70	42.91	42.70	42.81	42.69	42.57	0.237	0.56%
40	43.16	43.17	43.17	43.17	43.17	43.00	42.72	42.81	42.46	42.83	43.00	42.90	43.46	43.20	43.21	43.45	43.22	43.04	43.16	43.07	0.244	0.57%

Table A.20 Reflector effect factor results of each participant for used fuel case (45GWd/t, after 30,000 years)

Thickness [cm]	JAEA	GRS1	GRS2	GRS3	GRS4	VUJE	EDF1	EDF2	EDF3	EDF4	EDF5	EDF6	EMS1	EMS2	BFS	NCBJ1	NCBJ3	IRSN	EK	Ave.	SD	RSD (%)
H_2O mod.+ Dry SiO_2 ref.																						
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000	0.00%
10	22.02	21.86	21.86	21.86	21.86	21.75	22.01	22.25	21.65	21.99	22.14	22.05	22.06	21.85	21.83	22.11	21.82	21.74	21.94	21.93	0.153	0.70%
40	43.00	43.09	43.09	43.09	43.09	42.97	43.26	43.40	42.75	43.03	43.43	43.07	43.18	43.21	43.11	43.51	43.05	42.92	43.04	43.12	0.182	0.42%
120	51.70	51.72	51.72	51.72	51.72	51.72	51.75	51.78	51.27	51.89	52.24	51.76	51.85	51.86	51.79	52.25	51.67	51.81	51.75	51.79	0.205	0.40%
H_2O mod. + Wet SiO_2 ref.																						
10	45.27	44.86	44.86	44.86	44.86	44.80	44.87	45.01	44.51	44.82	45.27	44.83	44.96	44.94	44.88	45.19	44.81	45.05	44.97	44.93	0.179	0.40%
40	50.11	50.29	50.29	50.29	50.29	50.25	50.11	50.23	49.50	50.12	50.47	50.04	50.45	50.46	50.25	50.65	50.24	50.29	50.43	50.25	0.234	0.47%
H_2O mod. + H_2O ref.																						
10	41.57	43.01	43.01	43.01	43.01	43.14	42.55	42.69	42.64	42.81	43.24	42.65	43.27	43.16	43.01	43.25	42.98	42.85	43.12	42.89	0.386	0.90%
40	42.06	43.54	43.54	43.54	43.54	43.58	42.93	43.13	43.08	43.19	43.68	43.24	43.72	43.60	43.55	43.70	43.39	43.34	43.51	43.36	0.387	0.89%

Table A.21 Reflector effect results of each participant for used fuel case (45GWd/t, after 20 million years)

Thickness [cm]	JAEA	GRS1	GRS2	GRS3	GRS4	VUJE	EDF1	EDF2	EDF3	EDF4	EDF5	EDF6	EMS1	EMS2	BFS	NCBJ1	NCBJ3	IRSN	EK	Ave.	SD	RSD (%)
H_2O mod.+ Dry SiO_2 ref.																						
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.000	0.00%
10	22.06	22.16	22.16	22.16	22.16	22.00	22.60	22.48	21.94	22.35	22.30	22.38	22.39	22.15	22.07	22.48	22.18	22.37	22.28	22.25	0.179	0.80%
40	43.59	43.70	43.70	43.70	43.70	43.56	44.01	43.87	43.18	43.74	43.79	44.00	43.86	43.80	43.65	44.18	43.66	43.53	43.71	43.73	0.212	0.48%
120	52.21	52.25	52.25	52.25	52.25	52.18	52.37	52.22	51.60	52.51	52.47	52.64	52.54	52.30	52.16	52.85	52.27	51.96	52.26	52.29	0.260	0.50%
H_2O mod. + Wet SiO_2 ref.																						
10	45.91	45.75	45.75	45.75	45.75	45.61	45.96	45.84	45.51	45.94	45.92	45.96	46.04	45.77	45.83	46.18	45.72	45.21	45.95	45.81	0.213	0.46%
40	51.05	51.11	51.11	51.11	51.11	50.95	51.18	50.88	50.39	51.07	51.32	51.11	51.33	51.16	51.13	51.57	51.14	51.03	51.22	51.11	0.228	0.45%
H_2O mod. + H_2O ref.																						
10	45.19	43.91	43.91	43.91	43.91	43.77	43.69	43.53	43.51	43.88	43.97	43.76	44.31	43.96	43.87	44.21	43.83	43.81	44.09	43.95	0.358	0.82%
40	45.64	44.37	44.37	44.37	44.37	44.33	44.10	43.87	43.87	44.10	44.41	44.18	44.64	44.45	44.40	44.70	44.46	44.02	44.41	44.37	0.382	0.86%

Table A.22 Reaction rate of O-16 scattering results of each participant for fresh fuel case (1/2)

Thickness [cm]	JAEA	GRS1	GRS2	GRS3	GRS4	VUJE	EDF1	EDF2	EDF3	EDF4	EDF5	EDF6	EMS1	EMS2	BFS	NCBJ1	NCBJ3	IRSN	EK	Ave.	SD	RSD (%)
H_2O mod.+ Dry SiO_2 ref.																						
10	2.12E+00	2.16E+00	2.16E+00	2.13E+00	2.11E+00	2.11E+00	2.12E+00	2.12E+00	2.07E+00	2.12E+00	2.11E+00	2.12E+00	no data	2.11E+00	2.11E+00	2.12E+00	2.11E+00	2.13E+00	2.12E+00	2.12E+00	1.85E-02	0.87%
20	5.00E+00	5.14E+00	5.12E+00	5.07E+00	5.01E+00	5.02E+00	5.03E+00	5.01E+00	4.90E+00	5.00E+00	5.00E+00	5.01E+00	no data	5.01E+00	5.01E+00	5.00E+00	5.02E+00	5.02E+00	5.02E+00	5.02E+00	5.05E-02	1.01%
40	1.26E+01	1.30E+01	1.29E+01	1.28E+01	1.27E+01	1.27E+01	1.26E+01	1.26E+01	1.23E+01	1.26E+01	1.26E+01	1.26E+01	no data	1.27E+01	1.27E+01	1.26E+01	1.27E+01	1.26E+01	1.27E+01	1.27E+01	1.40E-01	1.10%
60	2.16E+01	2.21E+01	2.21E+01	2.20E+01	2.17E+01	2.17E+01	2.16E+01	2.16E+01	2.11E+01	2.15E+01	2.15E+01	2.16E+01	no data	2.17E+01	2.17E+01	2.16E+01	2.17E+01	2.16E+01	2.17E+01	2.17E+01	2.21E-01	1.02%
90	3.39E+01	3.42E+01	3.44E+01	3.44E+01	3.38E+01	3.38E+01	3.37E+01	3.36E+01	3.30E+01	3.36E+01	3.37E+01	3.37E+01	no data	3.38E+01	3.38E+01	3.38E+01	3.38E+01	3.37E+01	3.39E+01	3.38E+01	2.97E-01	0.88%
120	4.17E+01	4.19E+01	4.22E+01	4.23E+01	4.16E+01	4.16E+01	4.13E+01	4.12E+01	4.07E+01	4.16E+01	4.15E+01	4.15E+01	no data	4.16E+01	4.16E+01	4.17E+01	4.16E+01	4.17E+01	4.18E+01	4.16E+01	3.52E-01	0.85%
H_2O mod. + Wet SiO_2 ref.																						
10	3.87E+00	3.92E+00	3.93E+00	3.90E+00	3.83E+00	3.83E+00	3.89E+00	3.87E+00	3.81E+00	3.86E+00	3.83E+00	3.87E+00	no data	3.82E+00	3.83E+00	3.83E+00	3.83E+00	3.86E+00	3.87E+00	3.86E+00	3.55E-02	0.92%
20	7.34E+00	7.52E+00	7.53E+00	7.50E+00	7.34E+00	7.33E+00	7.41E+00	7.39E+00	7.27E+00	7.39E+00	7.34E+00	7.40E+00	no data	7.33E+00	7.34E+00	7.34E+00	7.34E+00	7.40E+00	7.42E+00	7.39E+00	7.18E-02	0.97%
40	9.06E+00	9.36E+00	9.38E+00	9.37E+00	9.18E+00	9.17E+00	9.19E+00	9.19E+00	9.03E+00	9.23E+00	9.18E+00	9.24E+00	no data	9.18E+00	9.18E+00	9.17E+00	9.18E+00	9.23E+00	9.28E+00	9.21E+00	9.23E-02	1.00%
60	9.23E+00	9.51E+00	9.54E+00	9.53E+00	9.34E+00	9.34E+00	9.37E+00	9.33E+00	9.17E+00	9.38E+00	9.34E+00	9.39E+00	no data	9.35E+00	9.33E+00	9.36E+00	9.34E+00	9.37E+00	9.45E+00	9.37E+00	9.30E-02	0.99%

Table A.22 Reaction rate of O-16 scattering results of each participant for fresh fuel case (2/2)

Thickness [cm]	JAEA	GRS1	GRS2	GRS3	GRS4	VUJE	EDF1	EDF2	EDF3	EDF4	EDF5	EDF6	EMS1	EMS2	BFS	NCBJ1	NCBJ3	IRSN	EK	Ave.	SD	RSD (%)
H_2O mod. + H_2O ref.																						
10	2.83E+00	2.87E+00	2.88E+00	2.87E+00	2.80E+00	2.80E+00	2.86E+00	2.85E+00	2.79E+00	2.83E+00	2.80E+00	2.84E+00	no data	2.80E+00	2.80E+00	2.81E+00	2.80E+00	2.83E+00	2.85E+00	2.83E+00	2.79E-02	0.99%
20	3.81E+00	3.87E+00	3.88E+00	3.86E+00	3.78E+00	3.79E+00	3.84E+00	3.84E+00	3.74E+00	3.81E+00	3.79E+00	3.82E+00	no data	3.79E+00	3.78E+00	3.79E+00	3.79E+00	3.82E+00	3.83E+00	3.81E+00	3.60E-02	0.94%
40	4.01E+00	4.05E+00	4.07E+00	4.05E+00	3.97E+00	3.98E+00	4.04E+00	4.03E+00	3.92E+00	3.99E+00	3.98E+00	4.01E+00	no data	3.97E+00	3.98E+00	3.99E+00	3.97E+00	4.00E+00	4.03E+00	4.00E+00	3.70E-02	0.93%
Wet SiO_2 mod. + Wet SiO_2 ref.																						
10	7.20E+00	7.34E+00	7.40E+00	7.36E+00	7.22E+00	7.22E+00	7.30E+00	7.27E+00	7.22E+00	7.29E+00	7.24E+00	7.31E+00	no data	7.22E+00	7.21E+00	7.23E+00	7.21E+00	7.29E+00	7.31E+00	7.27E+00	5.78E-02	0.80%
20	1.32E+01	1.36E+01	1.37E+01	1.37E+01	1.34E+01	1.34E+01	1.35E+01	1.35E+01	1.34E+01	1.35E+01	1.34E+01	1.35E+01	no data	1.34E+01	1.34E+01	1.35E+01	1.34E+01	1.36E+01	1.36E+01	1.35E+01	1.29E-01	0.96%
40	1.63E+01	1.69E+01	1.71E+01	1.71E+01	1.67E+01	1.67E+01	1.67E+01	1.67E+01	1.66E+01	1.68E+01	1.67E+01	1.68E+01	no data	1.67E+01	1.67E+01	1.67E+01	1.67E+01	1.69E+01	1.69E+01	1.68E+01	1.79E-01	1.07%
60	1.65E+01	1.72E+01	1.73E+01	1.73E+01	1.69E+01	1.70E+01	1.70E+01	1.69E+01	1.69E+01	1.71E+01	1.70E+01	1.71E+01	no data	1.69E+01	1.70E+01	1.70E+01	1.70E+01	1.72E+01	1.72E+01	1.70E+01	1.86E-01	1.10%

Table A.23 Reaction rate of Si-28 scattering results of each participant for fresh fuel case (1/2)

Thickness [cm]	JAEA	GRS1	GRS2	GRS3	GRS4	VUJE	EDF1	EDF2	EDF3	EDF4	EDF5	EDF6	EMS1	EMS2	BFS	NCBJ1	NCBJ3	IRSN	EK	Ave.	SD	RSD (%)
H_2O mod.+ Dry SiO_2 ref.																						
10	7.85E-01	8.00E-01	8.30E-01	8.25E-01	7.48E-01	7.67E-01	8.80E-01	8.82E-01	8.40E-01	7.59E-01	7.60E-01	7.63E-01	no data	7.67E-01	7.67E-01	8.46E-01	7.66E-01	7.80E-01	7.82E-01	7.97E-01	4.27E-02	5.36%
20	1.71E+00	1.81E+00	1.86E+00	1.85E+00	1.66E+00	1.69E+00	1.90E+00	1.90E+00	1.86E+00	1.66E+00	1.67E+00	1.67E+00	no data	1.69E+00	1.69E+00	1.84E+00	1.69E+00	1.70E+00	1.71E+00	1.75E+00	9.09E-02	5.18%
40	3.80E+00	4.19E+00	4.23E+00	4.23E+00	3.74E+00	3.78E+00	4.15E+00	4.15E+00	4.25E+00	3.71E+00	3.71E+00	3.73E+00	no data	3.78E+00	3.78E+00	4.07E+00	3.79E+00	3.76E+00	3.78E+00	3.92E+00	2.15E-01	5.49%
60	6.02E+00	6.73E+00	6.78E+00	6.80E+00	5.95E+00	6.00E+00	6.56E+00	6.56E+00	6.86E+00	5.91E+00	5.91E+00	5.93E+00	no data	6.01E+00	6.00E+00	6.48E+00	6.00E+00	5.97E+00	6.01E+00	6.25E+00	3.67E-01	5.87%
90	8.94E+00	9.97E+00	1.01E+01	1.01E+01	8.84E+00	8.89E+00	9.74E+00	9.74E+00	1.03E+01	8.78E+00	8.80E+00	8.80E+00	no data	8.88E+00	8.89E+00	9.61E+00	8.89E+00	8.84E+00	8.91E+00	9.28E+00	5.66E-01	6.10%
120	1.08E+01	1.20E+01	1.21E+01	1.23E+01	1.07E+01	1.07E+01	1.17E+01	1.17E+01	1.25E+01	1.07E+01	1.06E+01	1.06E+01	no data	1.07E+01	1.07E+01	1.16E+01	1.07E+01	1.07E+01	1.08E+01	1.12E+01	6.82E-01	6.09%
H_2O mod. + Wet SiO_2 ref.																						
10	7.98E-01	8.73E-01	8.74E-01	8.75E-01	7.74E-01	7.87E-01	8.95E-01	8.94E-01	9.04E-01	7.80E-01	7.77E-01	7.83E-01	no data	7.85E-01	7.86E-01	8.57E-01	7.87E-01	7.93E-01	7.97E-01	8.23E-01	4.93E-02	5.99%
20	1.41E+00	1.57E+00	1.57E+00	1.58E+00	1.39E+00	1.40E+00	1.59E+00	1.59E+00	1.63E+00	1.39E+00	1.39E+00	1.40E+00	no data	1.40E+00	1.40E+00	1.52E+00	1.40E+00	1.41E+00	1.42E+00	1.47E+00	9.24E-02	6.28%
40	1.70E+00	1.92E+00	1.93E+00	1.94E+00	1.70E+00	1.72E+00	1.94E+00	1.94E+00	2.00E+00	1.71E+00	1.70E+00	1.71E+00	no data	1.72E+00	1.72E+00	1.87E+00	1.72E+00	1.73E+00	1.74E+00	1.80E+00	1.12E-01	6.23%
60	1.73E+00	1.95E+00	1.96E+00	1.97E+00	1.73E+00	1.75E+00	1.97E+00	1.97E+00	2.03E+00	1.73E+00	1.73E+00	1.74E+00	no data	1.75E+00	1.74E+00	1.90E+00	1.75E+00	1.75E+00	1.77E+00	1.83E+00	1.14E-01	6.22%

Table A.23 Reaction rate of Si-28 scattering results of each participant for fresh fuel case (2/2)

Thickness [cm]	JAEA	GRS1	GRS2	GRS3	GRS4	VUJE	EDF1	EDF2	EDF3	EDF4	EDF5	EDF6	EMS1	EMS2	BFS	NCBJ1	NCBJ3	IRSN	EK	Ave.	SD	RSD (%)
Wet SiO_2 *mod.* + *Wet* SiO_2 *ref.*																						
10	1.49E+00	1.65E+00	1.66E+00	1.67E+00	1.47E+00	1.49E+00	1.70E+00	1.69E+00	1.73E+00	1.49E+00	1.48E+00	1.49E+00	no data	1.49E+00	1.49E+00	1.63E+00	1.49E+00	1.51E+00	1.52E+00	1.56E+00	9.35E-02	5.98%
20	2.54E+00	2.86E+00	2.88E+00	2.90E+00	2.53E+00	2.56E+00	2.90E+00	2.91E+00	3.02E+00	2.56E+00	2.54E+00	2.57E+00	no data	2.56E+00	2.56E+00	2.78E+00	2.56E+00	2.59E+00	2.60E+00	2.69E+00	1.71E-01	6.36%
40	3.07E+00	3.48E+00	3.51E+00	3.54E+00	3.10E+00	3.12E+00	3.53E+00	3.53E+00	3.68E+00	3.12E+00	3.11E+00	3.12E+00	no data	3.12E+00	3.12E+00	3.40E+00	3.12E+00	3.16E+00	3.17E+00	3.28E+00	2.09E-01	6.38%
60	3.11E+00	3.53E+00	3.56E+00	3.59E+00	3.14E+00	3.17E+00	3.58E+00	3.58E+00	3.73E+00	3.17E+00	3.16E+00	3.18E+00	no data	3.17E+00	3.17E+00	3.46E+00	3.17E+00	3.21E+00	3.22E+00	3.33E+00	2.11E-01	6.35%

Table A.24 Reaction rate of Si-28 capture results of each participant for fresh fuel case (1/2)

Thickness [cm]	JAEA	GRS1	GRS2	GRS3	GRS4	VUJE	EDF1	EDF2	EDF3	EDF4	EDF5	EDF6	EMS1	EMS2	BFS	NCBJ1	NCBJ3	IRSN	EK	Ave.	SD	RSD (%)
H_2O mod.+ Dry SiO_2 ref.																						
10	3.75E-03	4.22E-03	4.21E-03	4.23E-03	3.87E-03	3.87E-03	4.24E-03	4.25E-03	4.13E-03	3.76E-03	3.88E-03	3.89E-03	no data	3.88E-03	3.88E-03	4.19E-03	3.88E-03	3.10E-03	3.07E-03	3.91E-03	3.47E-04	8.88%
20	9.59E-03	1.07E-02	1.07E-02	1.07E-02	9.78E-03	9.80E-03	1.06E-02	1.07E-02	1.06E-02	9.58E-03	9.69E-03	9.82E-03	no data	9.79E-03	9.80E-03	1.05E-02	9.78E-03	8.72E-03	8.61E-03	9.97E-03	6.51E-04	6.53%
40	2.92E-02	3.30E-02	3.24E-02	3.22E-02	2.96E-02	2.96E-02	3.25E-02	3.23E-02	3.23E-02	2.95E-02	2.95E-02	2.96E-02	no data	2.96E-02	2.96E-02	3.17E-02	2.96E-02	2.83E-02	2.82E-02	3.05E-02	1.61E-03	5.27%
60	6.52E-02	7.29E-02	7.13E-02	7.08E-02	6.54E-02	6.55E-02	7.16E-02	7.14E-02	7.12E-02	6.54E-02	6.52E-02	6.55E-02	no data	6.55E-02	6.54E-02	7.00E-02	6.54E-02	6.40E-02	6.41E-02	6.76E-02	3.16E-03	4.68%
90	1.44E-01	1.56E-01	1.55E-01	1.55E-01	1.44E-01	1.43E-01	1.56E-01	1.55E-01	1.55E-01	1.44E-01	1.43E-01	1.44E-01	no data	1.43E-01	1.44E-01	1.53E-01	1.43E-01	1.43E-01	1.42E-01	1.48E-01	5.82E-03	3.93%
120	2.15E-01	2.29E-01	2.30E-01	2.31E-01	2.14E-01	2.15E-01	2.30E-01	2.30E-01	2.30E-01	2.16E-01	2.14E-01	2.15E-01	no data	2.14E-01	2.15E-01	2.29E-01	2.14E-01	2.14E-01	2.14E-01	2.21E-01	7.69E-03	3.49%
H_2O mod. + Wet SiO_2 ref.																						
10	2.39E-02	2.44E-02	2.45E-02	2.47E-02	2.34E-02	2.34E-02	2.59E-02	2.60E-02	2.63E-02	2.35E-02	2.34E-02	2.38E-02	no data	2.33E-02	2.34E-02	2.52E-02	2.34E-02	2.30E-02	2.30E-02	2.41E-02	1.07E-03	4.45%
20	5.83E-02	6.05E-02	6.07E-02	6.12E-02	5.81E-02	5.80E-02	6.40E-02	6.40E-02	6.43E-02	5.83E-02	5.80E-02	5.88E-02	no data	5.81E-02	5.81E-02	6.28E-02	5.81E-02	5.78E-02	5.77E-02	5.98E-02	2.43E-03	4.07%
40	7.66E-02	8.04E-02	8.08E-02	8.16E-02	7.76E-02	7.76E-02	8.46E-02	8.46E-02	8.51E-02	7.79E-02	7.75E-02	7.81E-02	no data	7.77E-02	7.77E-02	8.39E-02	7.76E-02	7.71E-02	7.72E-02	7.97E-02	3.02E-03	3.79%
60	7.83E-02	8.20E-02	8.25E-02	8.34E-02	7.94E-02	7.94E-02	8.67E-02	8.64E-02	8.71E-02	7.93E-02	7.92E-02	7.96E-02	no data	7.95E-02	7.93E-02	8.60E-02	7.94E-02	7.86E-02	7.90E-02	8.14E-02	3.14E-03	3.86%

Table A.24 Reaction rate of Si-28 capture results of each participant for fresh fuel case (2/2)

Thickness [cm]	JAEA	GRS1	GRS2	GRS3	GRS4	VUJE	EDF1	EDF2	EDF3	EDF4	EDF5	EDF6	EMS1	EMS2	BFS	NCBJ1	NCBJ3	IRSN	EK	Ave.	SD	RSD (%)
Wet SiO_2 mod. + Wet SiO_2 ref.																						
10	4.13E-02	4.23E-02	4.26E-02	4.30E-02	4.07E-02	4.07E-02	4.53E-02	4.51E-02	4.61E-02	4.10E-02	4.07E-02	4.12E-02	no data	4.07E-02	4.07E-02	4.40E-02	4.07E-02	4.02E-02	4.01E-02	4.20E-02	1.91E-03	4.53%
20	1.02E-01	1.07E-01	1.08E-01	1.09E-01	1.03E-01	1.03E-01	1.13E-01	1.14E-01	1.15E-01	1.04E-01	1.03E-01	1.04E-01	no data	1.03E-01	1.03E-01	1.11E-01	1.03E-01	1.03E-01	1.03E-01	1.06E-01	4.43E-03	4.17%
40	1.35E-01	1.42E-01	1.44E-01	1.46E-01	1.38E-01	1.38E-01	1.51E-01	1.51E-01	1.54E-01	1.39E-01	1.39E-01	1.39E-01	no data	1.38E-01	1.38E-01	1.50E-01	1.39E-01	1.39E-01	1.38E-01	1.42E-01	5.67E-03	3.99%
60	1.38E-01	1.45E-01	1.47E-01	1.49E-01	1.41E-01	1.45E-01	1.54E-01	1.54E-01	1.57E-01	1.42E-01	1.42E-01	1.43E-01	no data	1.41E-01	1.41E-01	1.53E-01	1.42E-01	1.42E-01	1.41E-01	1.45E-01	5.65E-03	3.89%

Table A.25 Reaction rate of H-1 scattering results of each participant for fresh fuel case (1/2)

Thickness [cm]	JAEA	GRS1	GRS2	GRS3	GRS4	VUJE	EDF1	EDF2	EDF3	EDF4	EDF5	EDF6	EMS1	EMS2	BFS	NCBJ1	NCBJ3	IRSN	EK	Ave.	SD	RSD (%)
H_2O mod. + Wet SiO_2 ref.																						
10	1.83E+01	1.75E+01	1.75E+01	1.78E+01	1.70E+01	1.70E+01	1.76E+01	1.76E+01	1.77E+01	1.76E+01	1.70E+01	1.76E+01	no data	1.70E+01	1.70E+01	1.71E+01	1.70E+01	1.76E+01	1.75E+01	1.74E+01	3.63E-01	2.08%
20	4.05E+01	3.93E+01	3.94E+01	4.00E+01	3.82E+01	3.81E+01	3.92E+01	3.92E+01	3.96E+01	3.94E+01	3.82E+01	3.95E+01	no data	3.81E+01	3.82E+01	3.83E+01	3.82E+01	3.94E+01	3.94E+01	3.90E+01	7.41E-01	1.90%
40	5.20E+01	5.10E+01	5.12E+01	5.21E+01	4.98E+01	4.98E+01	5.07E+01	5.08E+01	5.12E+01	5.13E+01	4.98E+01	5.14E+01	no data	4.97E+01	4.98E+01	4.99E+01	4.98E+01	5.12E+01	5.13E+01	5.07E+01	8.24E-01	1.63%
60	5.30E+01	5.20E+01	5.22E+01	5.32E+01	5.08E+01	5.08E+01	5.18E+01	5.17E+01	5.21E+01	5.23E+01	5.08E+01	5.24E+01	no data	5.08E+01	5.08E+01	5.11E+01	5.08E+01	5.22E+01	5.24E+01	5.17E+01	8.11E-01	1.57%
H_2O mod. + H_2O ref.																						
10	5.20E+01	5.14E+01	5.16E+01	5.24E+01	4.99E+01	4.99E+01	5.19E+01	5.19E+01	5.22E+01	5.19E+01	5.00E+01	5.20E+01	no data	4.99E+01	5.00E+01	5.03E+01	4.99E+01	5.16E+01	5.17E+01	5.11E+01	9.72E-01	1.90%
20	7.32E+01	7.24E+01	7.27E+01	7.38E+01	7.05E+01	7.06E+01	7.29E+01	7.30E+01	7.29E+01	7.28E+01	7.07E+01	7.31E+01	no data	7.05E+01	7.05E+01	7.10E+01	7.06E+01	7.29E+01	7.29E+01	7.21E+01	1.20E+00	1.67%
40	7.73E+01	7.62E+01	7.66E+01	7.78E+01	7.45E+01	7.45E+01	7.71E+01	7.70E+01	7.69E+01	7.68E+01	7.47E+01	7.72E+01	no data	7.43E+01	7.45E+01	7.51E+01	7.45E+01	7.68E+01	7.70E+01	7.60E+01	1.25E+00	1.64%

Table A.25 Reaction rate of H-1 scattering results of each participant for fresh fuel case (2/2)

Thickness [cm]	JAEA	GRS1	GRS2	GRS3	GRS4	VUJE	EDF1	EDF2	EDF3	EDF4	EDF5	EDF6	EMS1	EMS2	BFS	NCBJ1	NCBJ3	IRSN	EK	Ave.	SD	RSD (%)
Wet SiO_2 mod. + Wet SiO_2 ref.																						
10	3.28E+01	3.15E+01	3.18E+01	3.22E+01	3.09E+01	3.09E+01	3.18E+01	3.18E+01	3.24E+01	3.20E+01	3.11E+01	3.20E+01	no data	3.09E+01	3.09E+01	3.10E+01	3.09E+01	3.19E+01	3.18E+01	3.16E+01	6.00E-01	1.90%
20	7.19E+01	7.02E+01	7.09E+01	7.21E+01	6.87E+01	6.86E+01	7.05E+01	7.05E+01	7.19E+01	7.12E+01	6.89E+01	7.12E+01	no data	6.86E+01	6.87E+01	6.90E+01	6.87E+01	7.12E+01	7.11E+01	7.02E+01	1.31E+00	1.86%
40	9.26E+01	9.12E+01	9.22E+01	9.40E+01	8.96E+01	8.96E+01	9.14E+01	9.15E+01	9.31E+01	9.27E+01	9.00E+01	9.26E+01	no data	8.94E+01	8.95E+01	9.00E+01	8.96E+01	9.29E+01	9.26E+01	9.14E+01	1.52E+00	1.66%
60	9.41E+01	9.29E+01	9.40E+01	9.58E+01	9.13E+01	9.14E+01	9.31E+01	9.30E+01	9.48E+01	9.46E+01	9.18E+01	9.46E+01	no data	9.12E+01	9.14E+01	9.20E+01	9.14E+01	9.46E+01	9.45E+01	9.31E+01	1.52E+00	1.63%

Table A.26 Reaction rate of H-1 capture results of each participant for fresh fuel case (1/2)

Thickness [cm]	JAEA	GRS1	GRS2	GRS3	GRS4	VUJE	EDF1	EDF2	EDF3	EDF4	EDF5	EDF6	EMS1	EMS2	BFS	NCBJ1	NCBJ3	IRSN	EK	Ave.	SD	RSD (%)
H_2O mod. + Wet SiO_2 ref.																						
10	8.64E-02	8.27E-02	8.30E-02	8.36E-02	8.18E-02	8.20E-02	8.27E-02	8.26E-02	8.36E-02	8.30E-02	8.18E-02	8.29E-02	no data	8.17E-02	8.19E-02	8.16E-02	8.19E-02	8.28E-02	8.26E-02	8.27E-02	1.11E-03	1.35%
20	2.13E-01	2.08E-01	2.09E-01	2.11E-01	2.06E-01	2.06E-01	2.07E-01	2.06E-01	2.08E-01	2.08E-01	2.06E-01	2.08E-01	no data	2.06E-01	2.06E-01	2.06E-01	2.07E-01	2.08E-01	2.08E-01	2.08E-01	1.89E-03	0.91%
40	2.81E-01	2.78E-01	2.79E-01	2.82E-01	2.77E-01	2.77E-01	2.74E-01	2.75E-01	2.77E-01	2.78E-01	2.77E-01	2.78E-01	no data	2.77E-01	2.77E-01	2.76E-01	2.77E-01	2.78E-01	2.78E-01	2.77E-01	1.95E-03	0.70%
60	2.87E-01	2.84E-01	2.85E-01	2.88E-01	2.83E-01	2.83E-01	2.80E-01	2.80E-01	2.82E-01	2.84E-01	2.83E-01	2.84E-01	no data	2.83E-01	2.83E-01	2.83E-01	2.83E-01	2.83E-01	2.84E-01	2.83E-01	1.96E-03	0.69%
H_2O mod. + H_2O ref.																						
10	2.79E-01	2.78E-01	2.80E-01	2.82E-01	2.76E-01	2.76E-01	2.79E-01	2.79E-01	2.81E-01	2.79E-01	2.76E-01	2.80E-01	no data	2.76E-01	2.76E-01	2.76E-01	2.76E-01	2.78E-01	2.79E-01	2.78E-01	1.92E-03	0.69%
20	4.03E-01	4.02E-01	4.05E-01	4.07E-01	4.01E-01	4.01E-01	4.02E-01	4.03E-01	4.02E-01	4.03E-01	4.00E-01	4.04E-01	no data	4.01E-01	4.00E-01	4.01E-01	4.01E-01	4.03E-01	4.03E-01	4.02E-01	1.79E-03	0.44%
40	4.27E-01	4.25E-01	4.28E-01	4.31E-01	4.24E-01	4.25E-01	4.26E-01	4.26E-01	4.25E-01	4.26E-01	4.25E-01	4.28E-01	no data	4.24E-01	4.24E-01	4.25E-01	4.24E-01	4.26E-01	4.27E-01	4.26E-01	1.76E-03	0.41%

Table A.26 Reaction rate of H-1 capture results of each participant for fresh fuel case (2/2)

Thickness [cm]	JAEA	GRS1	GRS2	GRS3	GRS4	VUJE	EDF1	EDF2	EDF3	EDF4	EDF5	EDF6	EMS1	EMS2	BFS	NCBJ1	NCBJ3	IRSN	EK	Ave.	SD	RSD (%)
Wet SiO_2 mod. + Wet SiO_2 ref.																						
10	1.49E-01	1.43E-01	1.45E-01	1.46E-01	1.43E-01	1.43E-01	1.44E-01	1.44E-01	1.47E-01	1.45E-01	1.44E-01	1.45E-01	no data	1.43E-01	1.43E-01	1.43E-01	1.43E-01	1.44E-01	1.44E-01	1.44E-01	1.76E-03	1.22%
20	3.75E-01	3.68E-01	3.72E-01	3.76E-01	3.67E-01	3.67E-01	3.67E-01	3.67E-01	3.74E-01	3.71E-01	3.68E-01	3.71E-01	no data	3.67E-01	3.67E-01	3.66E-01	3.67E-01	3.71E-01	3.71E-01	3.70E-01	3.06E-03	0.83%
40	4.96E-01	4.93E-01	4.99E-01	5.05E-01	4.94E-01	4.94E-01	4.90E-01	4.90E-01	4.99E-01	4.99E-01	4.95E-01	4.98E-01	no data	4.94E-01	4.94E-01	4.94E-01	4.94E-01	5.00E-01	4.98E-01	4.96E-01	3.63E-03	0.73%
60	5.05E-01	5.03E-01	5.09E-01	5.16E-01	5.05E-01	5.05E-01	5.00E-01	5.00E-01	5.10E-01	5.09E-01	5.06E-01	5.09E-01	no data	5.05E-01	5.05E-01	5.05E-01	5.05E-01	5.10E-01	5.09E-01	5.07E-01	3.86E-03	0.76%

Table A.27 Absorption / Production results of each participant for fresh fuel case (1/2)

Thickness [cm]	JAEA	GRS1	GRS2	GRS3	GRS4	VUJE	EDF1	EDF2	EDF3	EDF4	EDF5	EDF6	EMS1	EMS2	BFS	NCBJ1	NCBJ3	IRSN	EK	Ave.	SD	RSD (%)
H_2O mod.+ Dry SiO_2 ref.																						
0	6.81E-01	6.87E-01	6.88E-01	6.88E-01	6.85E-01	6.85E-01	6.83E-01	6.82E-01	6.83E-01	6.83E-01	6.83E-01	6.85E-01	6.84E-01	6.85E-01	6.85E-01	6.83E-01	6.80E-01	6.85E-01	6.83E-01	6.84E-01	2.18E-03	0.32%
10	6.88E-01	6.94E-01	6.95E-01	6.94E-01	6.91E-01	6.91E-01	6.89E-01	6.90E-01	6.89E-01	6.90E-01	6.89E-01	6.91E-01	6.89E-01	6.92E-01	6.91E-01	6.89E-01	6.86E-01	6.91E-01	6.89E-01	6.90E-01	2.18E-03	0.32%
20	6.94E-01	7.01E-01	7.01E-01	7.01E-01	6.98E-01	6.98E-01	6.97E-01	6.96E-01	6.95E-01	6.96E-01	6.95E-01	6.97E-01	6.96E-01	6.98E-01	6.98E-01	6.96E-01	6.92E-01	6.98E-01	6.96E-01	6.97E-01	2.37E-03	0.34%
40	7.15E-01	7.22E-01	7.22E-01	7.22E-01	7.18E-01	7.18E-01	7.17E-01	7.17E-01	7.17E-01	7.17E-01	7.16E-01	7.18E-01	7.17E-01	7.19E-01	7.18E-01	7.16E-01	7.11E-01	7.18E-01	7.16E-01	7.18E-01	2.58E-03	0.36%
60	7.52E-01	7.60E-01	7.59E-01	7.59E-01	7.55E-01	7.56E-01	7.55E-01	7.55E-01	7.54E-01	7.53E-01	7.53E-01	7.55E-01	7.53E-01	7.55E-01	7.55E-01	7.53E-01	7.45E-01	7.54E-01	7.53E-01	7.54E-01	3.21E-03	0.43%
90	8.35E-01	8.42E-01	8.41E-01	8.41E-01	8.37E-01	8.37E-01	8.37E-01	8.37E-01	8.36E-01	8.35E-01	8.34E-01	8.36E-01	8.35E-01	8.37E-01	8.37E-01	8.34E-01	8.21E-01	8.37E-01	8.35E-01	8.36E-01	4.18E-03	0.50%
120	9.10E-01	9.14E-01	9.16E-01	9.16E-01	9.12E-01	9.12E-01	9.12E-01	9.12E-01	9.11E-01	9.11E-01	9.10E-01	9.12E-01	9.10E-01	9.12E-01	9.12E-01	9.10E-01	8.92E-01	9.12E-01	9.11E-01	9.11E-01	4.88E-03	0.54%
H_2O mod. + Wet SiO_2 ref.																						
10	7.72E-01	7.72E-01	7.73E-01	7.73E-01	7.69E-01	7.69E-01	7.70E-01	7.70E-01	7.71E-01	7.69E-01	7.67E-01	7.71E-01	7.67E-01	7.69E-01	7.69E-01	7.68E-01	7.63E-01	7.70E-01	7.68E-01	7.69E-01	2.28E-03	0.30%
20	9.32E-01	9.30E-01	9.32E-01	9.34E-01	9.27E-01	9.27E-01	9.29E-01	9.29E-01	9.30E-01	9.27E-01	9.25E-01	9.29E-01	9.25E-01	9.27E-01	9.27E-01	9.26E-01	9.19E-01	9.29E-01	9.27E-01	9.28E-01	3.17E-03	0.34%
40	1.02E+00	1.02E+00	1.02E+00	1.03E+00	1.02E+00	1.02E+00	1.02E+00	1.02E+00	1.02E+00	1.02E+00	1.02E+00	1.02E+00	1.02E+00	1.02E+00	1.02E+00	1.02E+00	1.01E+00	1.02E+00	1.02E+00	1.02E+00	3.14E-03	0.31%
60	1.03E+00	1.03E+00	1.03E+00	1.03E+00	1.03E+00	1.03E+00	1.03E+00	1.03E+00	1.03E+00	1.03E+00	1.02E+00	1.03E+00	1.03E+00	1.03E+00	1.03E+00	1.03E+00	1.02E+00	1.03E+00	1.03E+00	1.03E+00	3.00E-03	0.29%

Table A.27 Absorption / Production results of each participant for fresh fuel case (2/2)

Thickness [cm]	JAEA	GRS1	GRS2	GRS3	GRS4	VUJE	EDF1	EDF2	EDF3	EDF4	EDF5	EDF6	EMS1	EMS2	BFS	NCBJ1	NCBJ3	IRSN	EK	Ave.	SD	RSD (%)
H_2O *mod.* + H_2O *ref.*																						
10	9.30E-01	9.34E-01	9.36E-01	9.37E-01	9.29E-01	9.29E-01	9.32E-01	9.31E-01	9.33E-01	9.31E-01	9.28E-01	9.33E-01	9.27E-01	9.29E-01	9.29E-01	9.28E-01	9.25E-01	9.31E-01	9.31E-01	9.31E-01	3.02E-03	0.32%
20	1.05E+00	1.06E+00	1.06E+00	1.06E+00	1.05E+00	1.05E+00	1.05E+00	1.05E+00	1.05E+00	1.06E+00	1.05E+00	1.06E+00	1.05E+00	1.05E+00	1.05E+00	1.05E+00	1.05E+00	1.06E+00	1.05E+00	1.05E+00	3.00E-03	0.28%
40	1.08E+00	1.08E+00	1.08E+00	1.09E+00	1.08E+00	1.08E+00	1.08E+00	1.08E+00	1.08E+00	1.08E+00	1.08E+00	1.08E+00	1.08E+00	1.08E+00	1.08E+00	1.08E+00	1.07E+00	1.08E+00	1.08E+00	1.08E+00	2.89E-03	0.27%
Wet SiO_2 *mod.* + *Wet* SiO_2 *ref.*																						
0	7.87E-01	7.99E-01	8.01E-01	8.00E-01	7.96E-01	7.96E-01	7.95E-01	7.92E-01	7.95E-01	7.96E-01	7.95E-01	7.98E-01	7.95E-01	7.96E-01	7.96E-01	7.94E-01	7.85E-01	7.97E-01	7.99E-01	7.95E-01	4.05E-03	0.51%
10	8.90E-01	8.90E-01	8.92E-01	8.93E-01	8.88E-01	8.87E-01	8.91E-01	8.91E-01	8.93E-01	8.89E-01	8.87E-01	8.91E-01	8.86E-01	8.88E-01	8.87E-01	8.87E-01	8.78E-01	8.91E-01	8.97E-01	8.89E-01	3.95E-03	0.44%
20	1.17E+00	1.17E+00	1.17E+00	1.18E+00	1.17E+00	1.17E+00	1.17E+00	1.17E+00	1.18E+00	1.17E+00	1.17E+00	1.17E+00	1.17E+00	1.17E+00	1.17E+00	1.17E+00	1.15E+00	1.17E+00	1.18E+00	1.17E+00	6.01E-03	0.51%
40	1.33E+00	1.33E+00	1.34E+00	1.34E+00	1.33E+00	1.33E+00	1.33E+00	1.33E+00	1.34E+00	1.34E+00	1.33E+00	1.34E+00	1.33E+00	1.33E+00	1.33E+00	1.33E+00	1.32E+00	1.34E+00	1.34E+00	1.33E+00	6.62E-03	0.50%
60	1.34E+00	1.34E+00	1.35E+00	1.36E+00	1.34E+00	1.35E+00	1.35E+00	1.35E+00	1.36E+00	1.35E+00	1.35E+00	1.35E+00	1.35E+00	1.34E+00	1.35E+00	1.35E+00	1.33E+00	1.35E+00	1.36E+00	1.35E+00	6.90E-03	0.51%

Table A.28 Leakage / Production results of each participant for fresh fuel case (1/2)

Thickness [cm]	JAEA	GRS1	GRS2	GRS3	GRS4	VUJE	EDF1	EDF2	EDF3	EDF4	EDF5	EDF6	EMS1	EMS2	BFS	NCBJ1	NCBJ3	IRSN	EK	Ave.	SD	RSD (%)
H_2O mod.+ Dry SiO_2 ref.																						
0	8.5E-01	8.5E-01	8.5E-01	8.5E-01	8.4E-01	8.4E-01	8.4E-01	8.4E-01	8.4E-01	8.4E-01	8.4E-01	8.5E-01	8.5E-01	8.4E-01	8.4E-01	8.5E-01	8.5E-01	8.5E-01	8.5E-01	8.5E-01	3.62E-03	0.43%
10	5.7E-01	5.6E-01	5.6E-01	5.7E-01	5.6E-01	5.6E-01	5.6E-01	5.6E-01	5.6E-01	5.6E-01	5.6E-01	5.6E-01	5.6E-01	5.6E-01	5.6E-01	5.6E-01	5.7E-01	5.6E-01	5.6E-01	5.6E-01	2.71E-03	0.48%
20	4.6E-01	4.5E-01	4.6E-01	4.6E-01	4.6E-01	4.6E-01	4.5E-01	4.5E-01	4.6E-01	4.6E-01	4.6E-01	4.6E-01	4.6E-01	4.6E-01	4.6E-01	4.6E-01	4.6E-01	4.6E-01	4.6E-01	4.6E-01	2.82E-03	0.62%
40	3.5E-01	3.4E-01	3.5E-01	3.5E-01	3.5E-01	3.5E-01	3.5E-01	3.5E-01	3.5E-01	3.5E-01	3.5E-01	3.5E-01	3.5E-01	3.5E-01	3.5E-01	3.5E-01	3.6E-01	3.5E-01	3.5E-01	3.5E-01	2.92E-03	0.84%
60	2.8E-01	2.7E-01	2.7E-01	2.8E-01	2.7E-01	2.7E-01	2.7E-01	2.7E-01	2.8E-01	2.7E-01	2.7E-01	2.7E-01	2.8E-01	2.7E-01	2.7E-01	2.8E-01	2.8E-01	2.8E-01	2.8E-01	2.7E-01	3.31E-03	1.21%
90	1.8E-01	1.7E-01	1.7E-01	1.7E-01	1.7E-01	1.7E-01	1.7E-01	1.7E-01	1.7E-01	1.7E-01	1.7E-01	1.7E-01	1.7E-01	1.7E-01	1.7E-01	1.7E-01	1.9E-01	1.7E-01	1.8E-01	1.7E-01	4.08E-03	2.35%
120	9.7E-02	9.0E-02	9.2E-02	9.5E-02	9.4E-02	9.4E-02	9.1E-02	9.2E-02	9.5E-02	9.4E-02	9.4E-02	9.4E-02	9.6E-02	9.4E-02	9.4E-02	9.5E-02	1.1E-01	9.5E-02	9.6E-02	9.5E-02	4.81E-03	5.06%
H_2O mod. + Wet SiO_2 ref.																						
10	2.9E-01	2.9E-01	2.9E-01	3.0E-01	2.9E-01	3.0E-01	2.9E-01	2.9E-01	2.9E-01	2.9E-01	3.0E-01	2.9E-01	3.0E-01	2.9E-01	2.9E-01	3.0E-01	3.0E-01	3.0E-01	3.0E-01	2.9E-01	2.39E-03	0.81%
20	9.7E-02	9.9E-02	1.0E-01	1.0E-01	1.0E-01	1.0E-01	9.8E-02	9.9E-02	9.9E-02	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.0E-01	1.1E-01	1.0E-01	1.0E-01	1.0E-01	2.41E-03	2.39%
40	8.1E-03	7.4E-03	7.5E-03	7.7E-03	8.0E-03	8.1E-03	8.2E-03	7.8E-03	8.0E-03	8.0E-03	8.2E-03	8.4E-03	8.3E-03	8.0E-03	8.0E-03	7.6E-03	1.7E-02	8.1E-03	8.0E-03	8.5E-03	2.18E-03	25.73%
60	2.3E-04	-1.8E-04	-1.2E-04	-3.1E-04	-8.0E-05	9.5E-05	3.1E-04	-1.1E-04	3.1E-04	5.3E-04	3.1E-04	5.3E-04	-3.2E-05	-1.8E-04	2.7E-03	-2.4E-05	9.3E-03	1.5E-04	5.4E-05	7.1E-04	2.18E-03	307.40%

Table A.28 Leakage / Production results of each participant for fresh fuel case (2/2)

Thickness [cm]	JAEA	GRS1	GRS2	GRS3	GRS4	VUJE	EDF1	EDF2	EDF3	EDF4	EDF5	EDF6	EMS1	EMS2	BFS	NCBJ1	NCBJ3	IRSN	EK	Ave.	SD	RSD (%)
H_2O mod. + H_2O ref.																						
10	1.5E-01	1.5E-01	1.5E-01	1.5E-01	1.5E-01	1.5E-01	1.5E-01	1.5E-01	1.5E-01	1.5E-01	1.5E-01	1.5E-01	1.5E-01	1.5E-01	1.5E-01	1.5E-01	1.6E-01	1.5E-01	1.5E-01	1.5E-01	1.66E-03	1.09%
20	2.5E-02	2.3E-02	2.3E-02	2.4E-02	2.4E-02	2.4E-02	2.4E-02	2.4E-02	2.3E-02	2.3E-02	2.4E-02	2.4E-02	2.4E-02	2.4E-02	2.4E-02	2.5E-02	2.8E-02	2.3E-02	2.4E-02	2.4E-02	1.15E-03	4.77%
40	8.1E-04	5.9E-05	1.2E-04	1.5E-04	1.8E-04	-2.3E-04	7.9E-04	8.0E-04	4.4E-04	-8.5E-06	-1.3E-04	3.2E-04	7.9E-05	1.9E-04	1.6E-04	3.5E-04	4.8E-03	4.5E-04	8.1E-05	5.0E-04	1.09E-03	218.94%
Wet SiO_2 mod. + Wet SiO_2 ref.																						
0	2.4E+00	2.4E+00	2.5E+00	2.5E+00	2.5E+00	2.5E+00	2.4E+00	2.4E+00	2.5E+00	2.5E+00	2.5E+00	2.5E+00	2.5E+00	2.5E+00	2.5E+00	2.5E+00	2.5E+00	2.5E+00	2.5E+00	2.5E+00	2.13E-02	0.86%
10	5.5E-01	5.6E-01	5.7E-01	5.8E-01	5.7E-01	5.7E-01	5.6E-01	5.6E-01	5.7E-01	5.7E-01	5.7E-01	5.7E-01	5.7E-01	5.7E-01	5.7E-01	5.7E-01	5.8E-01	5.7E-01	5.6E-01	5.7E-01	5.88E-03	1.03%
20	1.8E-01	1.8E-01	1.8E-01	1.8E-01	1.8E-01	1.8E-01	1.8E-01	1.8E-01	1.8E-01	1.8E-01	1.8E-01	1.8E-01	1.9E-01	1.8E-01	1.8E-01	1.8E-01	2.0E-01	1.8E-01	1.7E-01	1.8E-01	4.56E-03	2.50%
40	1.5E-02	1.3E-02	1.3E-02	1.3E-02	1.4E-02	1.4E-02	1.3E-02	1.4E-02	1.5E-02	1.4E-02	1.4E-02	1.3E-02	1.5E-02	1.4E-02	1.4E-02	1.3E-02	2.9E-02	1.5E-02	5.0E-03	1.4E-02	4.16E-03	29.14%
60	2.2E-03	1.4E-05	1.0E-04	-4.2E-04	1.6E-04	1.1E-04	8.1E-04	6.3E-04	5.4E-04	4.0E-04	1.2E-03	6.4E-04	3.3E-04	3.4E-05	2.6E-04	6.3E-05	1.5E-02	-3.0E-04	-9.7E-03	6.4E-04	4.24E-03	660.65%

Table A.29 Result of extended reflector thickness case (Dry SiO2 reflector for flesh fuel case)

Thickness [cm]	k_{eff}	A/P	L/P
0	0.6546	6.81E-01	8.47E-01
10	0.7971	6.88E-01	5.66E-01
20	0.8651	6.94E-01	4.62E-01
40	0.9365	7.15E-01	3.52E-01
60	0.9714	7.52E-01	2.77E-01
90	0.9895	8.35E-01	1.76E-01
120	0.9938	9.10E-01	9.68E-02
130	0.9946	9.29E-01	7.69E-02
140	0.9957	9.44E-01	6.06E-02
150	0.9957	9.57E-01	4.71E-02
200	0.9953	9.93E-01	1.20E-02
250	0.9958	1.00E+00	3.03E-03
300	0.9950	1.00E+00	5.02E-04

Table A.30 SI_{th} results of each participant for fresh fuel case (1/2)

Thickness [cm]	JAEA	GRS1	GRS2	GRS3	GRS4	VUJE	EDF1	EDF2	EDF3	EDF4	EDF5	EDF6	EMS1	EMS2	BFS	NCBJ1	NCBJ3	IRSN	EK	Ave.	SD	RSD (%)
H_2O mod.+ Dry SiO_2 ref.																						
0	1.22E-01	1.17E-01	1.17E-01	1.16E-01	1.17E-01	1.20E-01	1.21E-01	1.21E-01	1.22E-01	1.21E-01	1.20E-01	1.21E-01	1.20E-01	1.20E-01	1.20E-01	1.20E-01	1.20E-01	1.21E-01	1.21E-01	1.20E-01	1.71E-03	1.43%
10	1.31E-01	1.27E-01	1.28E-01	1.27E-01	1.27E-01	1.30E-01	1.32E-01	1.32E-01	1.33E-01	1.32E-01	1.31E-01	1.31E-01	1.31E-01	1.30E-01	1.30E-01	1.30E-01	1.30E-01	1.32E-01	1.31E-01	1.30E-01	1.72E-03	1.32%
20	1.36E-01	1.33E-01	1.33E-01	1.33E-01	1.33E-01	1.36E-01	1.38E-01	1.38E-01	1.38E-01	1.38E-01	1.36E-01	1.37E-01	1.36E-01	1.36E-01	1.36E-01	1.36E-01	1.36E-01	1.38E-01	1.37E-01	1.36E-01	1.75E-03	1.28%
40	1.43E-01	1.41E-01	1.41E-01	1.40E-01	1.40E-01	1.43E-01	1.45E-01	1.45E-01	1.46E-01	1.45E-01	1.44E-01	1.45E-01	1.44E-01	1.43E-01	1.43E-01	1.43E-01	1.43E-01	1.45E-01	1.44E-01	1.43E-01	1.75E-03	1.22%
60	1.47E-01	1.45E-01	1.45E-01	1.44E-01	1.44E-01	1.48E-01	1.49E-01	1.49E-01	1.50E-01	1.49E-01	1.48E-01	1.49E-01	1.48E-01	1.47E-01	1.48E-01	1.48E-01	1.48E-01	1.49E-01	1.49E-01	1.48E-01	1.76E-03	1.19%
90	1.49E-01	1.47E-01	1.47E-01	1.47E-01	1.47E-01	1.50E-01	1.52E-01	1.52E-01	1.52E-01	1.52E-01	1.51E-01	1.52E-01	1.51E-01	1.50E-01	1.50E-01	1.50E-01	1.50E-01	1.52E-01	1.51E-01	1.50E-01	1.78E-03	1.19%
120	1.49E-01	1.48E-01	1.48E-01	1.47E-01	1.47E-01	1.51E-01	1.52E-01	1.52E-01	1.53E-01	1.52E-01	1.51E-01	1.52E-01	1.51E-01	1.51E-01	1.51E-01	1.51E-01	1.51E-01	1.52E-01	1.52E-01	1.51E-01	1.77E-03	1.18%
H_2O mod. + Wet SiO_2 ref.																						
10	1.55E-01	1.55E-01	1.55E-01	1.54E-01	1.55E-01	1.58E-01	1.60E-01	1.60E-01	1.61E-01	1.60E-01	1.59E-01	1.60E-01	1.59E-01	1.58E-01	1.58E-01	1.58E-01	1.58E-01	1.60E-01	1.59E-01	1.58E-01	2.07E-03	1.31%
20	1.59E-01	1.60E-01	1.60E-01	1.59E-01	1.60E-01	1.63E-01	1.65E-01	1.65E-01	1.66E-01	1.65E-01	1.64E-01	1.65E-01	1.64E-01	1.63E-01	1.63E-01	1.63E-01	1.63E-01	1.65E-01	1.68E-01	1.63E-01	2.47E-03	1.51%
40	1.59E-01	1.60E-01	1.60E-01	1.60E-01	1.60E-01	1.64E-01	1.65E-01	1.65E-01	1.66E-01	1.65E-01	1.64E-01	1.65E-01	1.64E-01	1.64E-01	1.64E-01	1.64E-01	1.64E-01	1.65E-01	1.69E-01	1.63E-01	2.57E-03	1.57%
60	1.59E-01	1.60E-01	1.60E-01	1.60E-01	1.60E-01	1.63E-01	1.65E-01	1.65E-01	1.66E-01	1.65E-01	1.64E-01	1.65E-01	1.64E-01	1.64E-01	1.64E-01	1.64E-01	1.63E-01	1.65E-01	1.69E-01	1.63E-01	2.56E-03	1.57%

Table A.30 SI_{th} results of each participant for fresh fuel case (2/2)

Thickness [cm]	JAEA	GRS1	GRS2	GRS3	GRS4	VUJE	EDF1	EDF2	EDF3	EDF4	EDF5	EDF6	EMS1	EMS2	BFS	NCBJ1	NCBJ3	IRSN	EK	Ave.	SD	RSD (%)
H_2O mod. + H_2O ref.																						
10	1.60E-01	1.61E-01	1.61E-01	1.61E-01	1.61E-01	1.65E-01	1.66E-01	1.66E-01	1.67E-01	1.67E-01	1.66E-01	1.66E-01	1.66E-01	1.65E-01	1.65E-01	1.65E-01	1.65E-01	1.67E-01	1.66E-01	1.65E-01	2.34E-03	1.42%
20	1.61E-01	1.62E-01	1.62E-01	1.61E-01	1.62E-01	1.65E-01	1.67E-01	1.67E-01	1.68E-01	1.67E-01	1.66E-01	1.67E-01	1.66E-01	1.65E-01	1.66E-01	1.66E-01	1.66E-01	1.67E-01	1.67E-01	1.65E-01	2.31E-03	1.40%
40	1.60E-01	1.62E-01	1.62E-01	1.61E-01	1.62E-01	1.66E-01	1.67E-01	1.67E-01	1.68E-01	1.67E-01	1.66E-01	1.67E-01	1.66E-01	1.66E-01	1.66E-01	1.66E-01	1.66E-01	1.67E-01	1.67E-01	1.65E-01	2.33E-03	1.41%
Wet SiO_2 mod. + Wet SiO_2 ref.																						
0	4.43E-02	3.59E-02	3.53E-02	3.51E-02	3.57E-02	3.63E-02	3.69E-02	3.69E-02	3.67E-02	3.67E-02	3.64E-02	3.64E-02	3.64E-02	3.62E-02	3.63E-02	3.62E-02	3.63E-02	3.64E-02	3.43E-02	3.66E-02	1.99E-03	5.44%
10	9.22E-02	8.45E-02	8.41E-02	8.38E-02	8.41E-02	8.55E-02	8.64E-02	8.64E-02	8.65E-02	8.65E-02	8.59E-02	8.62E-02	8.59E-02	8.55E-02	8.55E-02	8.56E-02	8.55E-02	8.65E-02	8.41E-02	8.58E-02	1.79E-03	2.09%
20	9.78E-02	9.13E-02	9.10E-02	9.06E-02	9.10E-02	9.25E-02	9.31E-02	9.31E-02	9.33E-02	9.34E-02	9.28E-02	9.31E-02	9.29E-02	9.25E-02	9.25E-02	9.25E-02	9.25E-02	9.34E-02	9.62E-02	9.29E-02	1.71E-03	1.84%
40	9.81E-02	9.16E-02	9.13E-02	9.09E-02	9.14E-02	9.29E-02	9.34E-02	9.34E-02	9.36E-02	9.36E-02	9.31E-02	9.35E-02	9.33E-02	9.29E-02	9.29E-02	9.29E-02	9.28E-02	9.36E-02	9.80E-02	9.33E-02	1.86E-03	1.99%
60	9.82E-02	9.17E-02	9.13E-02	9.10E-02	9.14E-02	9.29E-02	9.35E-02	9.34E-02	9.36E-02	9.37E-02	9.30E-02	9.34E-02	9.33E-02	9.29E-02	9.29E-02	9.29E-02	9.29E-02	9.35E-02	9.80E-02	9.33E-02	1.88E-03	2.01%

Figure A.1 k_{eff} against reflector thickness (H_2O moderator and dry SiO_2 reflector for fresh fuel case)

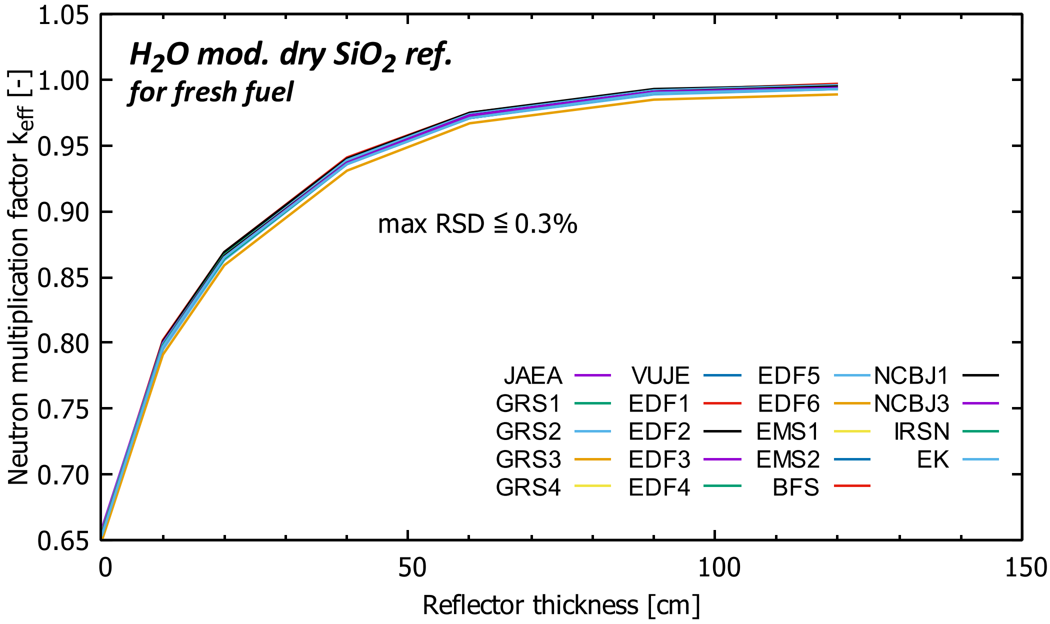


Figure A.2 k_{eff} against reflector thickness (H_2O moderator and wet SiO_2 reflector for fresh fuel case)

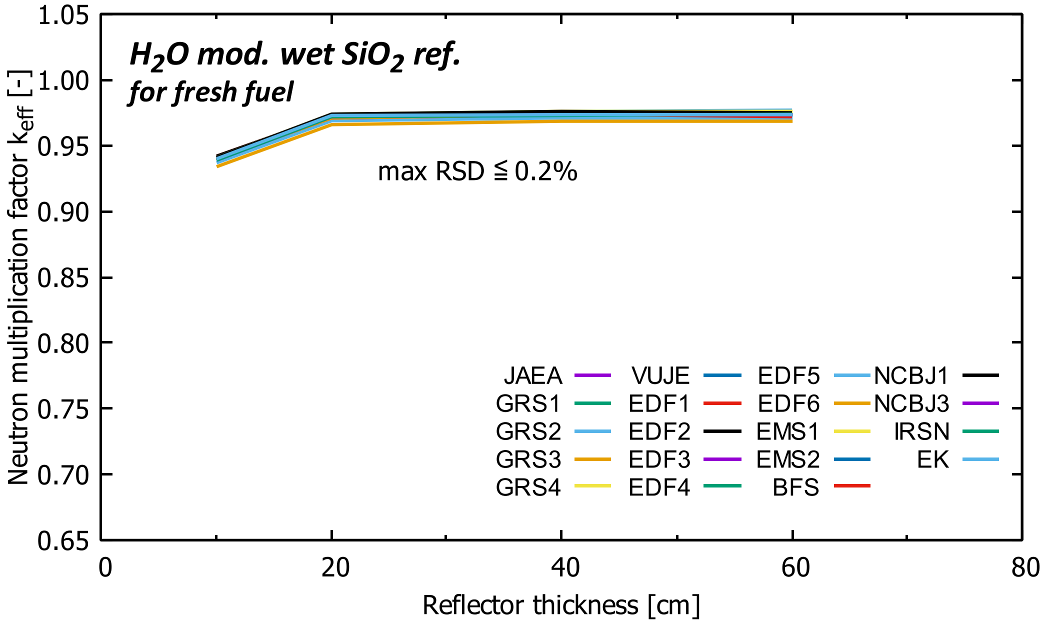


Figure A.3 k_{eff} against reflector thickness (H_2O moderator and H_2O reflector for fresh fuel case)

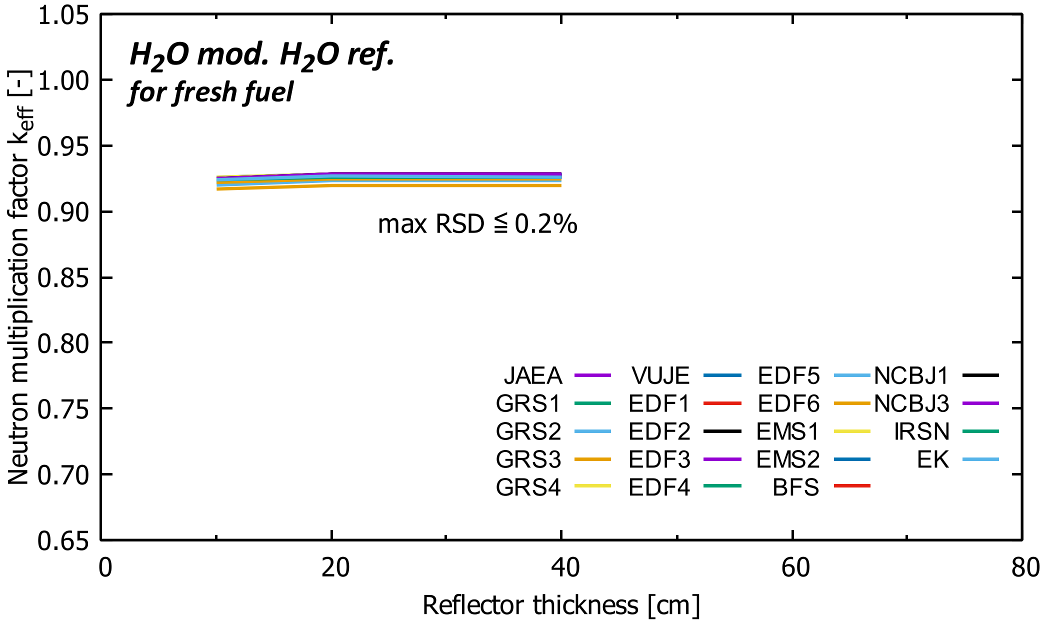


Figure A.4 k_{eff} against reflector thickness (wet SiO_2 moderator and wet SiO_2 reflector for fresh fuel case)

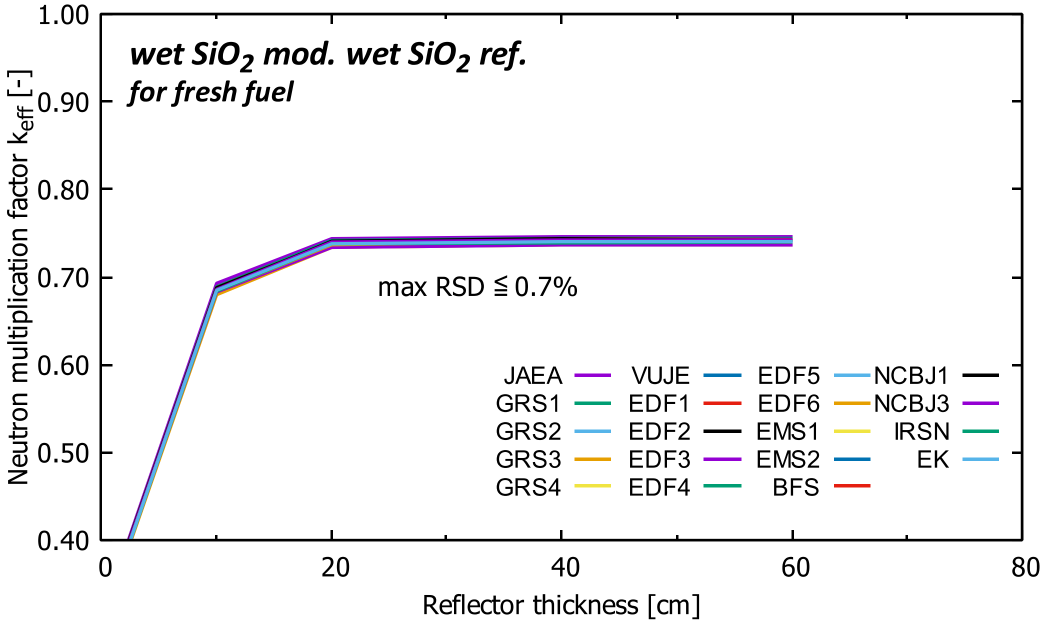


Figure A.5 k_{eff} against reflector thickness (30 GWd/t, after 0 year, H_2O moderator and dry SiO_2 reflector for used fuel case)

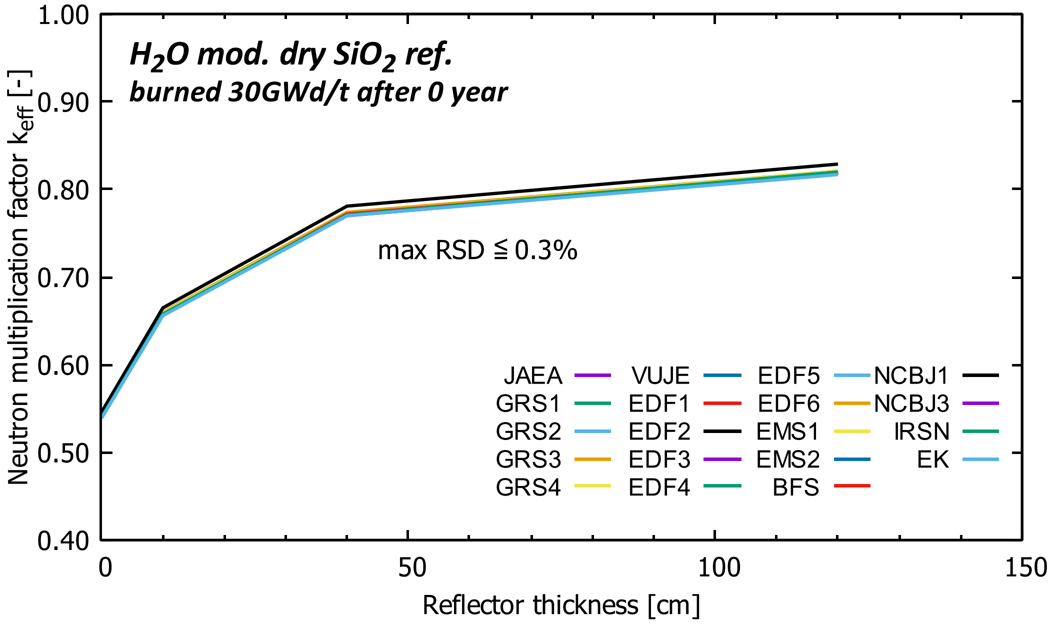


Figure A.6 k_{eff} against reflector thickness (30 GWd/t, after 0 year, H_2O moderator and wet SiO_2 reflector for used fuel case)

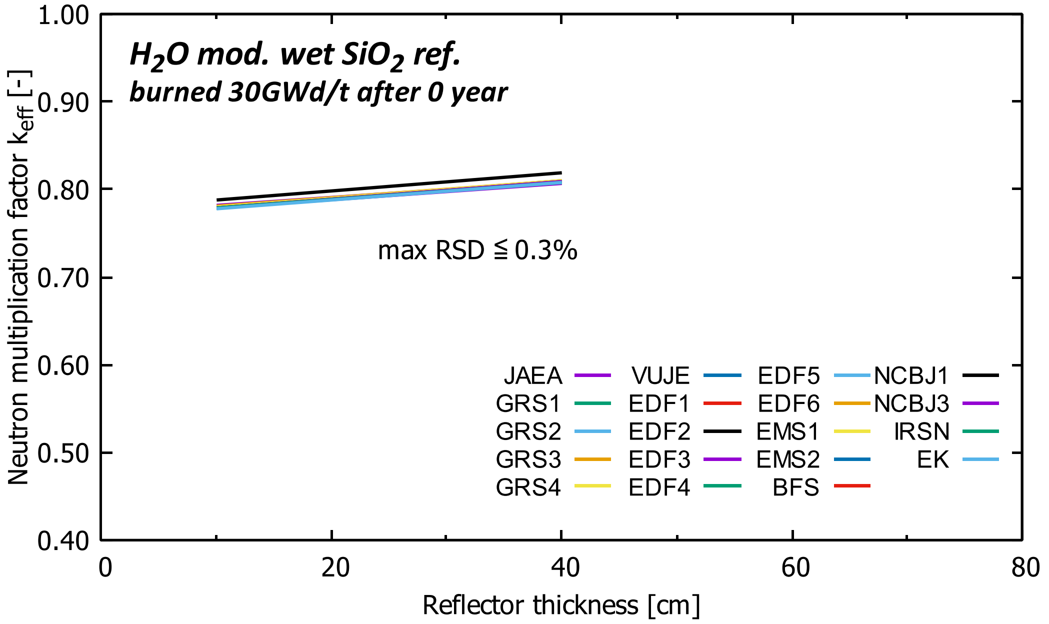


Figure A.7 k_{eff} against reflector thickness (30 GWd/t, after 0 year, H_2O moderator and H_2O reflector for used fuel case)

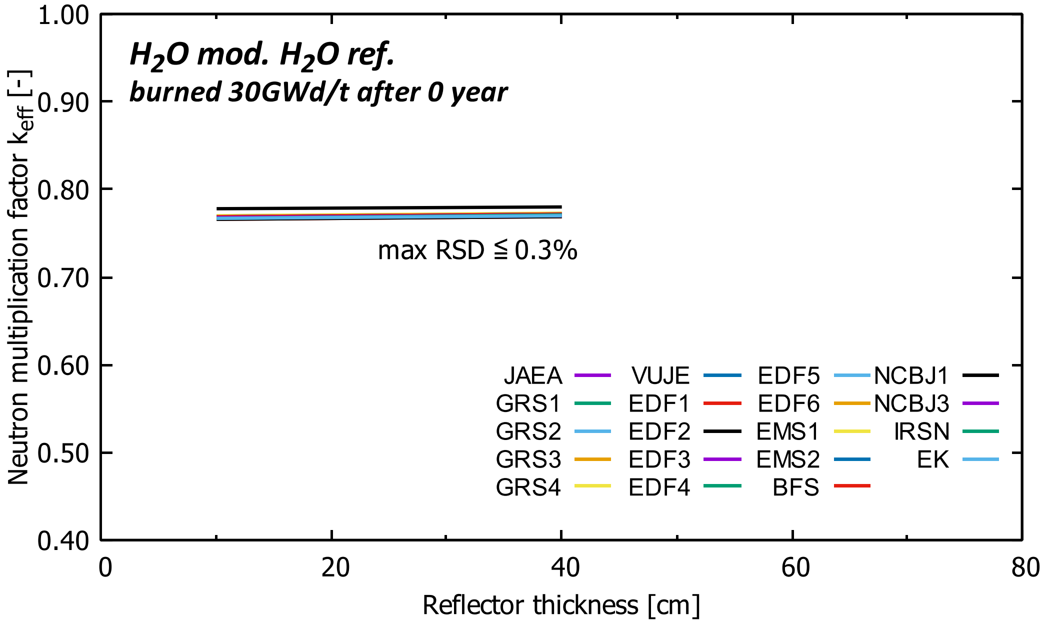


Figure A.8 k_{eff} against reflector thickness (30 GWd/t, after 30 000 year, H_2O moderator and dry SiO_2 reflector for used fuel case)

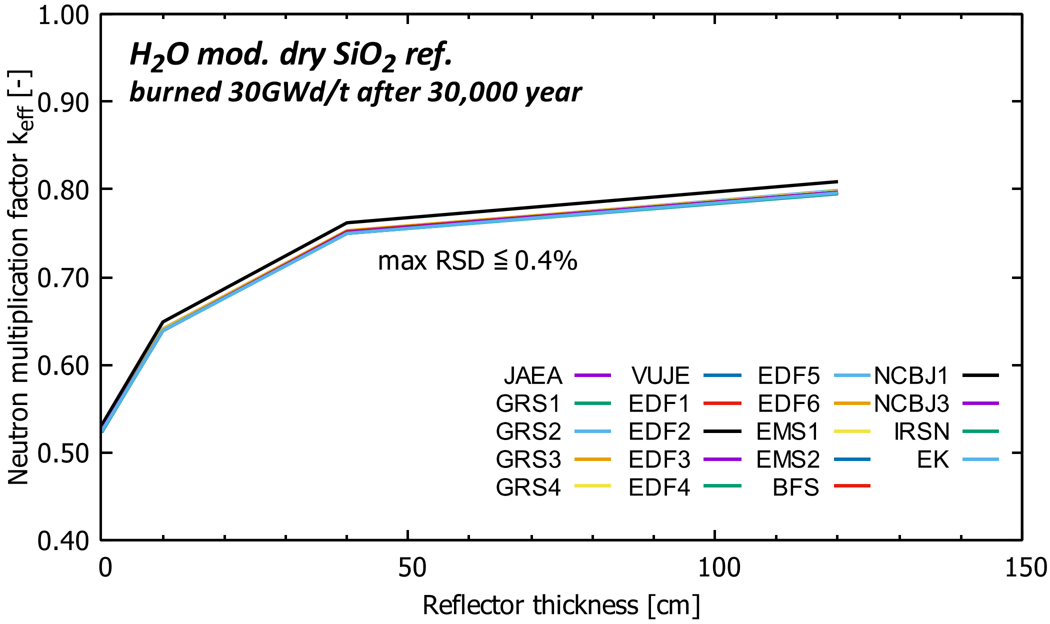


Figure A.9 k_{eff} against reflector thickness (30 GWd/t, after 30 000 year, H_2O moderator and wet SiO_2 reflector for used fuel case)

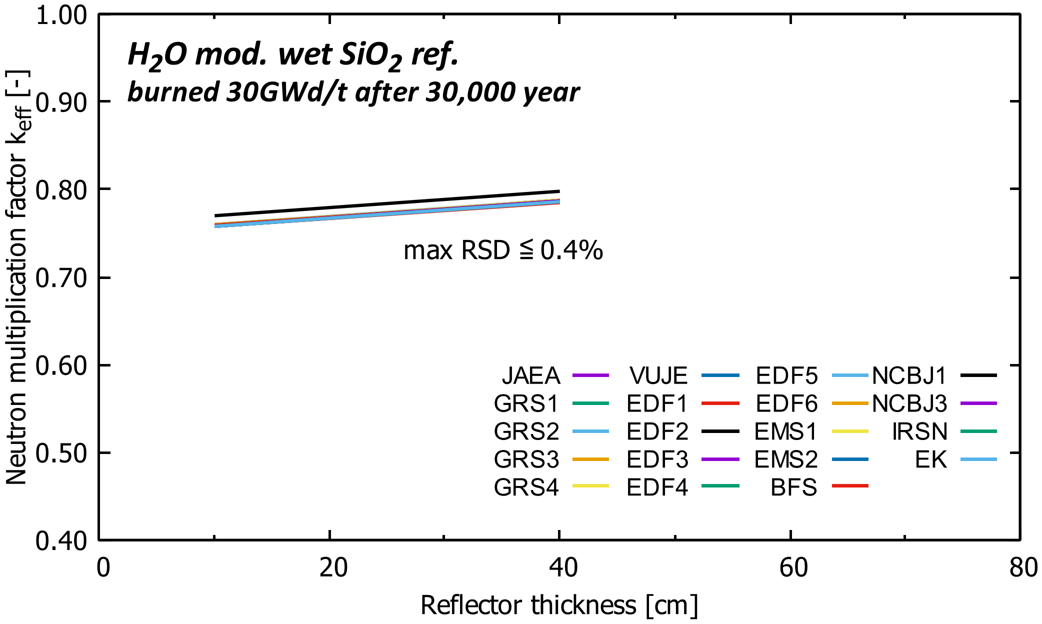


Figure A.10 k_{eff} against reflector thickness (30 GWd/t, after 30 000 year, H_2O moderator and H_2O reflector for used fuel case)

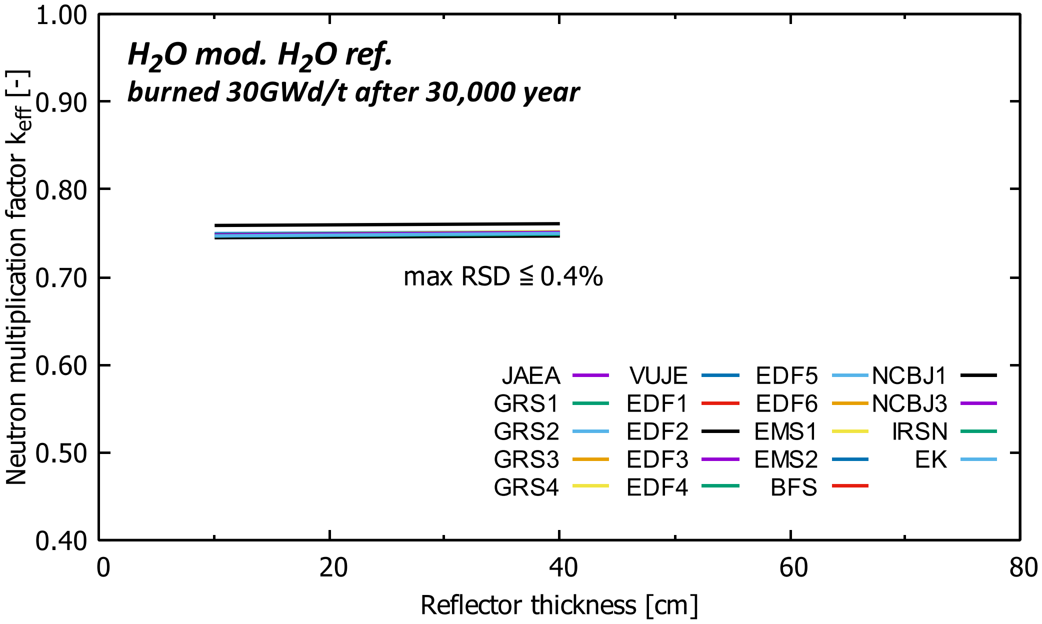


Figure A.11 k_{eff} against reflector thickness (30 GWd/t, after 20 million year, H_2O moderator and dry SiO_2 reflector for used fuel case)

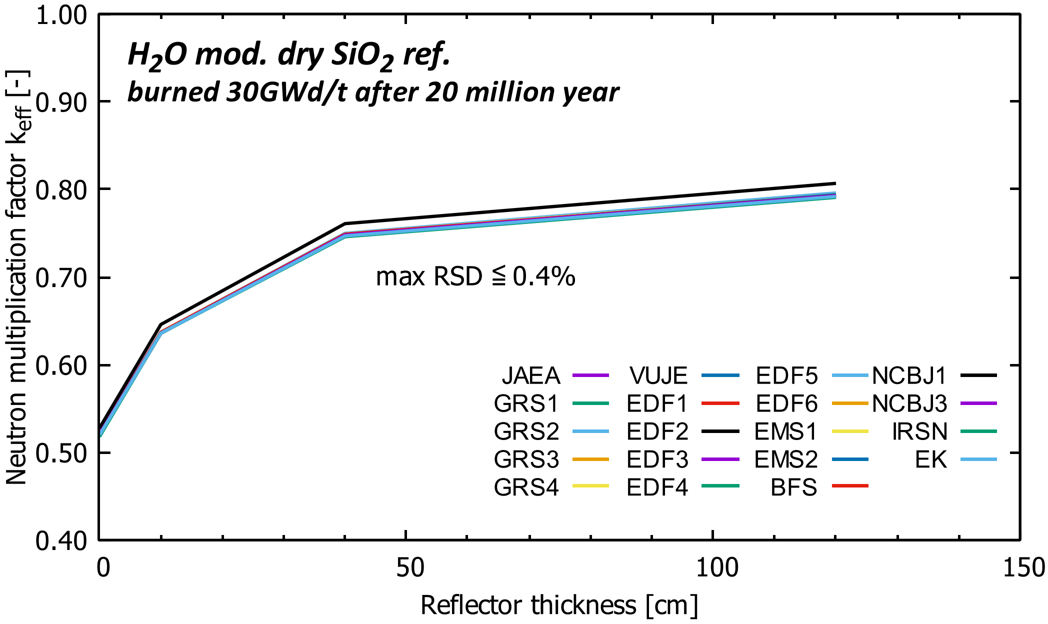


Figure A.12 k_{eff} against reflector thickness (30 GWd/t, after 20 million year, H_2O moderator and wet SiO_2 reflector for used fuel case)

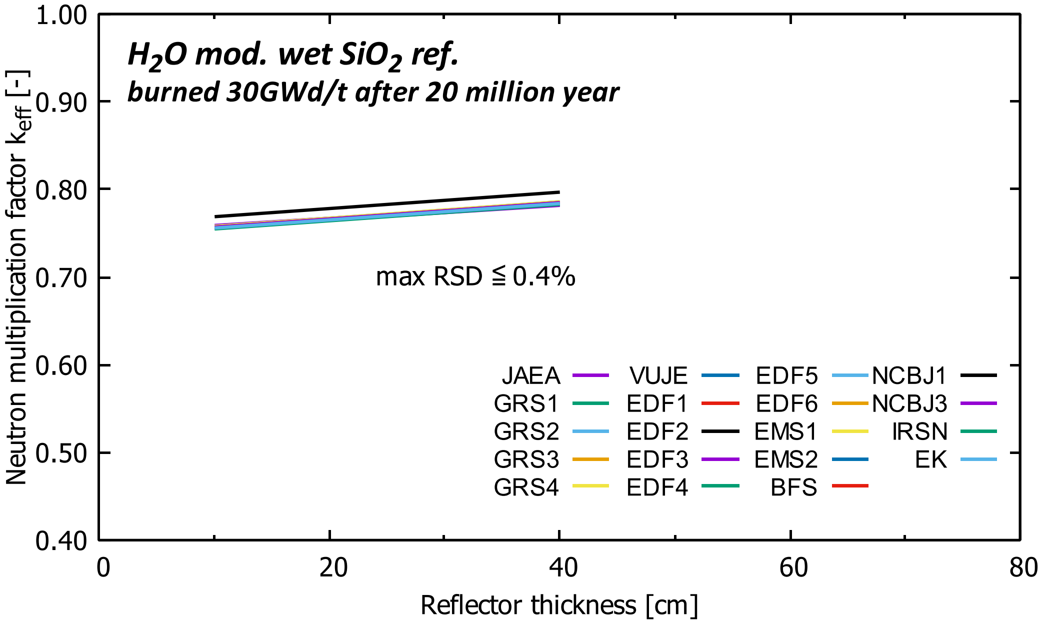


Figure A.13 k_{eff} against reflector thickness (30 GWd/t, after 20 million year, H_2O moderator and H_2O reflector for used fuel case)

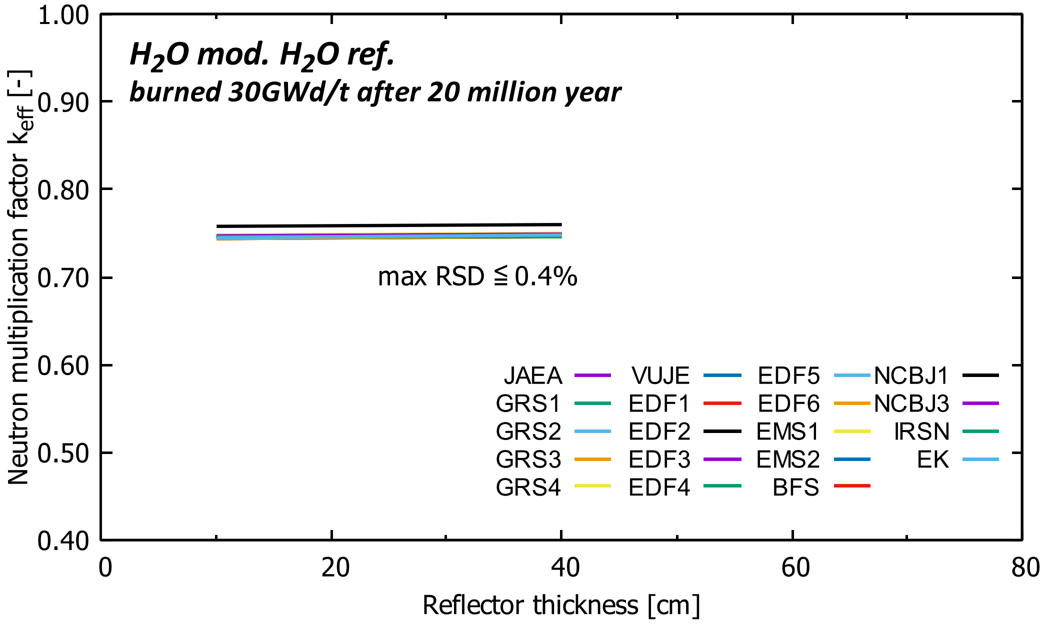


Figure A.14 k_{eff} against reflector thickness (45 GWd/t, after 0 year, H_2O moderator and dry SiO_2 reflector for used fuel case)

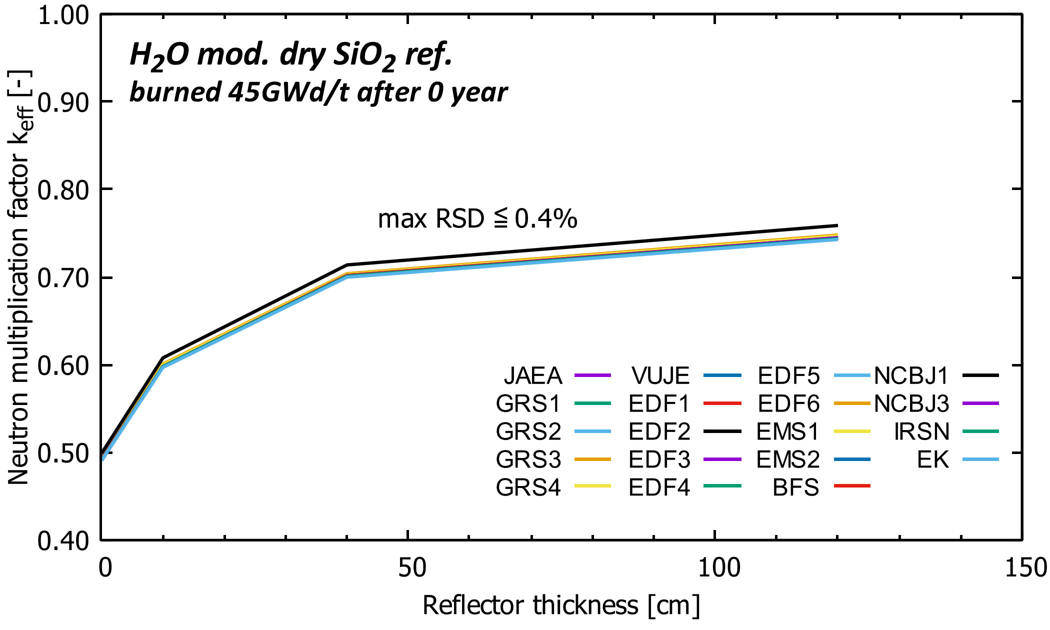


Figure A.15 k_{eff} against reflector thickness (45 GWd/t, after 0 year, H_2O moderator and wet SiO_2 reflector for used fuel case)

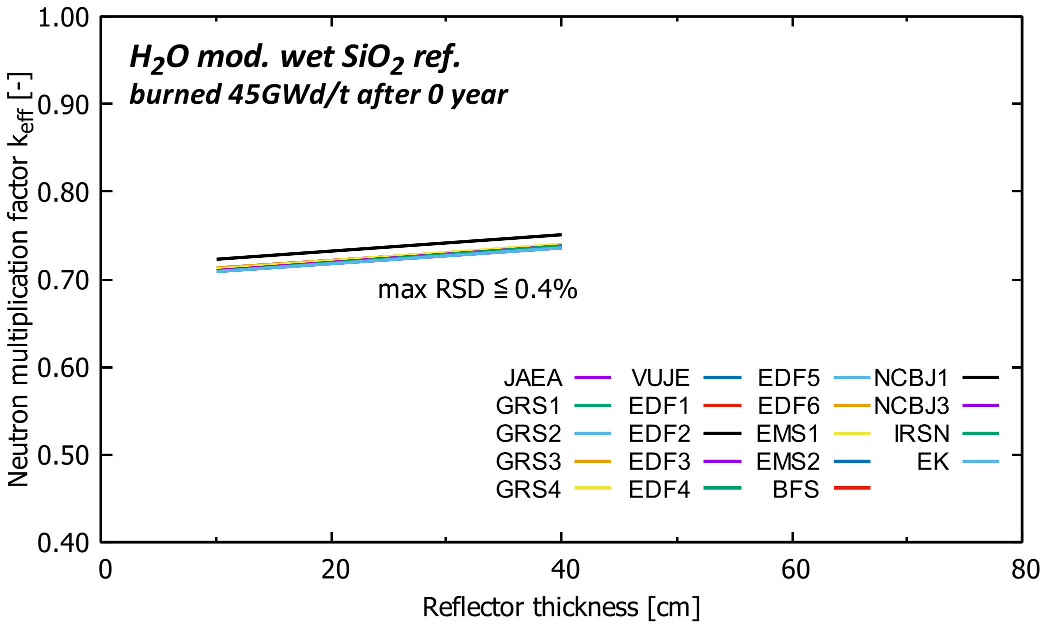


Figure A.16 k_{eff} against reflector thickness (45 GWd/t, after 0 year, H_2O moderator and H_2O reflector for used fuel case)

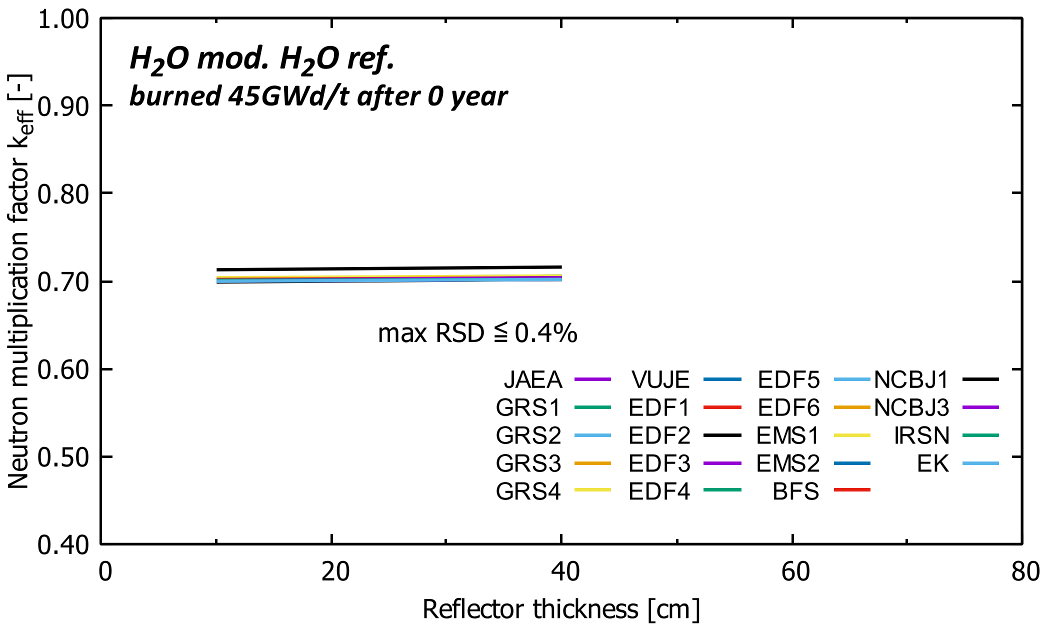


Figure A.17 k_{eff} against reflector thickness (45 GWd/t, after 30 000 year, H_2O moderator and dry SiO_2 reflector for used fuel case)

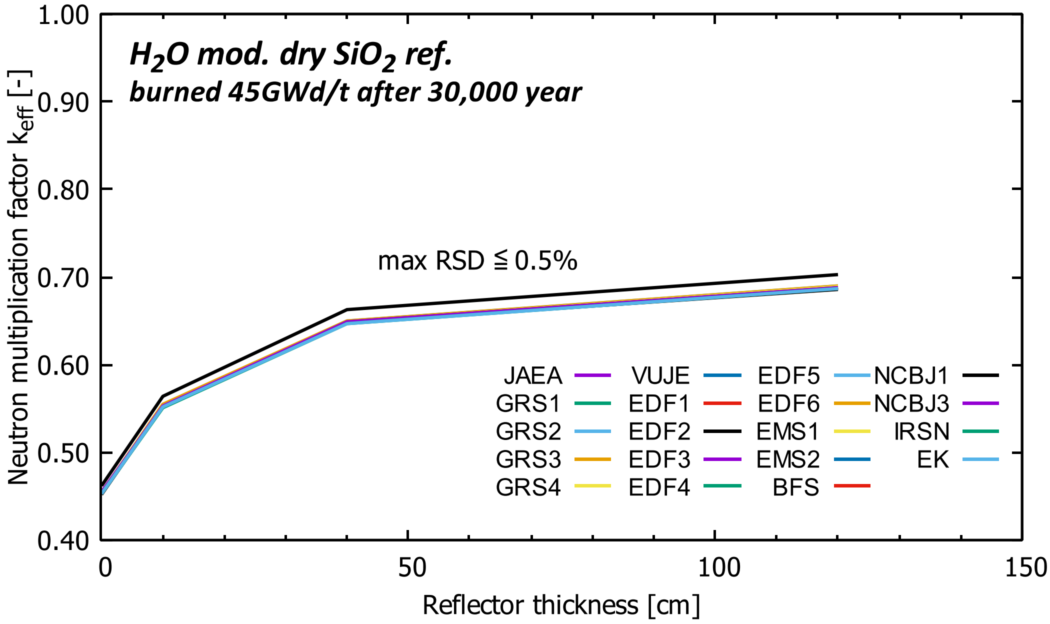


Figure A.18 k_{eff} against reflector thickness (45 GWd/t, after 30 000 year, H_2O moderator and wet SiO_2 reflector for used fuel case)

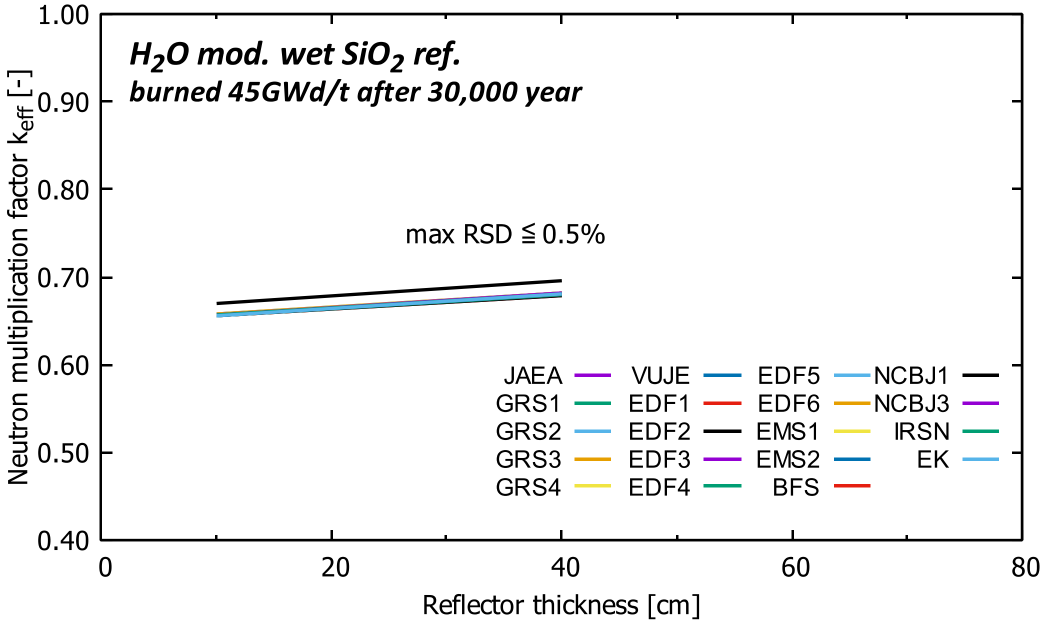


Figure A.19 k_{eff} against reflector thickness (45 GWd/t, after 30 000 year, H_2O moderator and H_2O reflector for used fuel case)

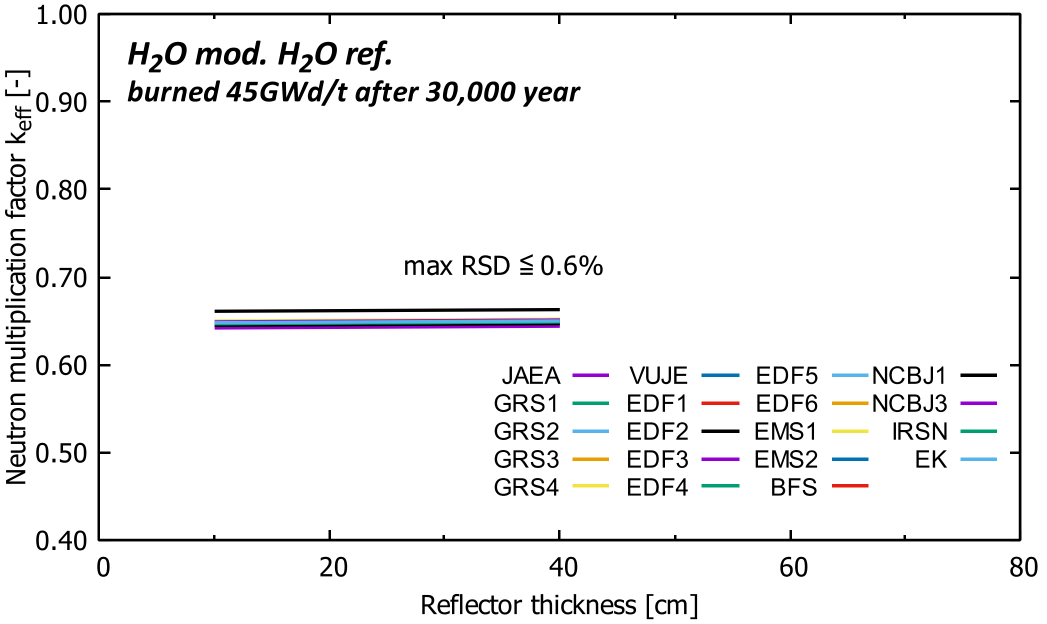


Figure A.20 k_{eff} against reflector thickness (45 GWd/t, after 20 million year, H_2O moderator and dry SiO_2 reflector for used fuel case)

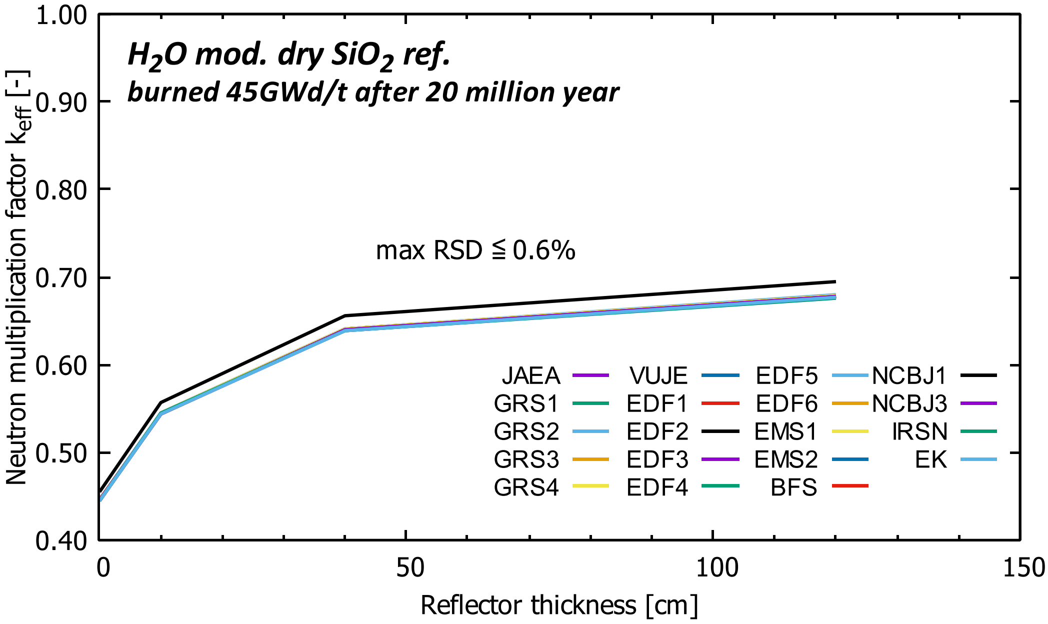


Figure A.21 k_{eff} against reflector thickness (45 GWd/t, after 20 million year, H_2O moderator and wet SiO_2 reflector for used fuel case)

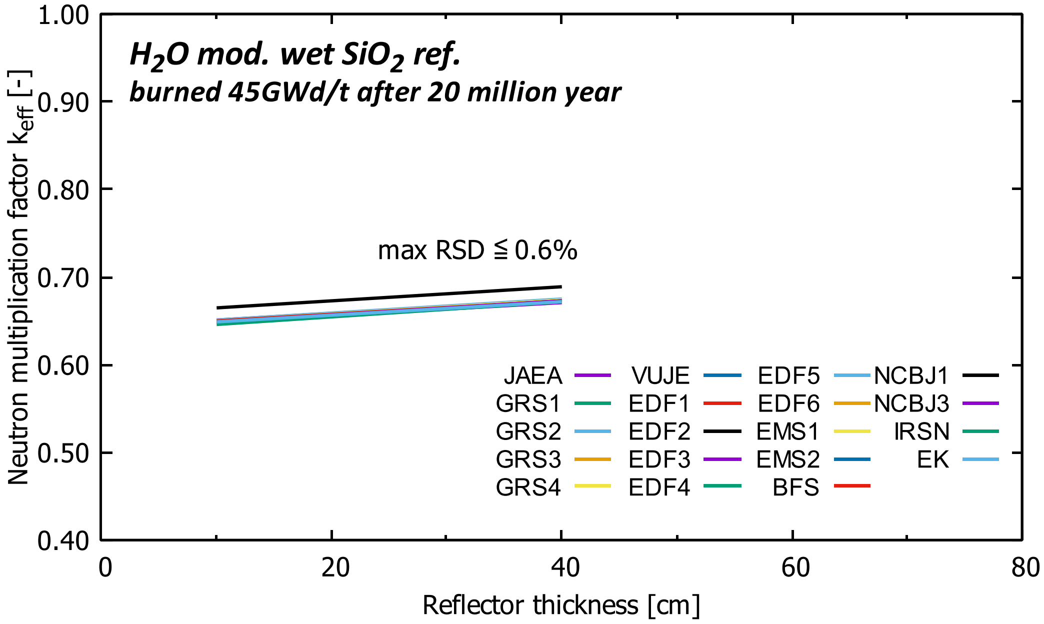


Figure A.22 k_{eff} against reflector thickness (45 GWd/t, after 20 million year, H_2O moderator and H_2O reflector for used fuel case)

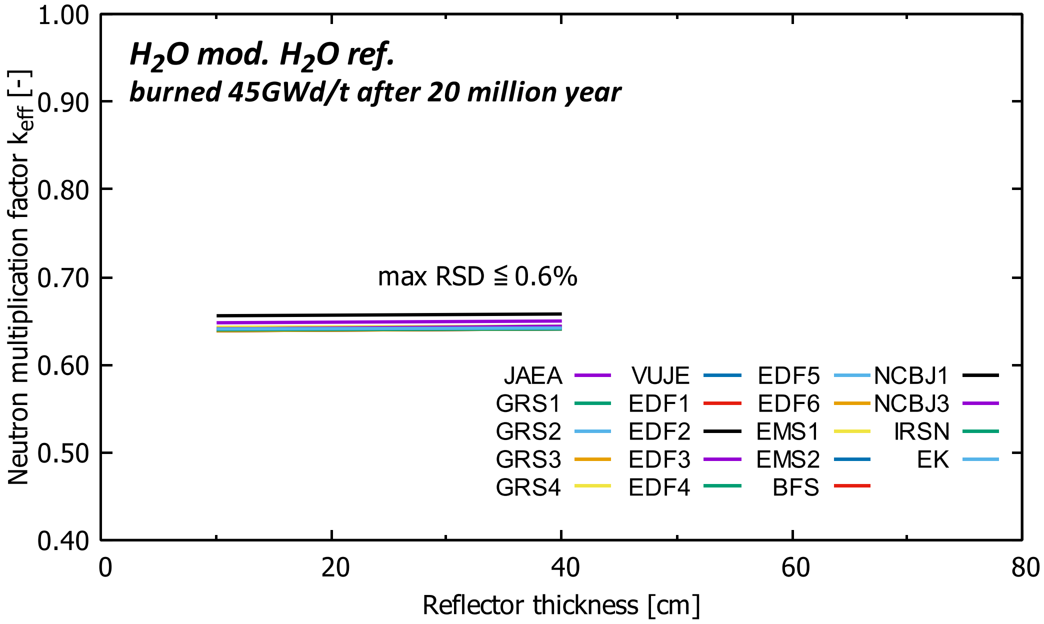


Figure A.23 Difference of k_{eff} of each participant from the average over all participants (H_2O moderator and dry SiO_2 reflector for fresh fuel case)

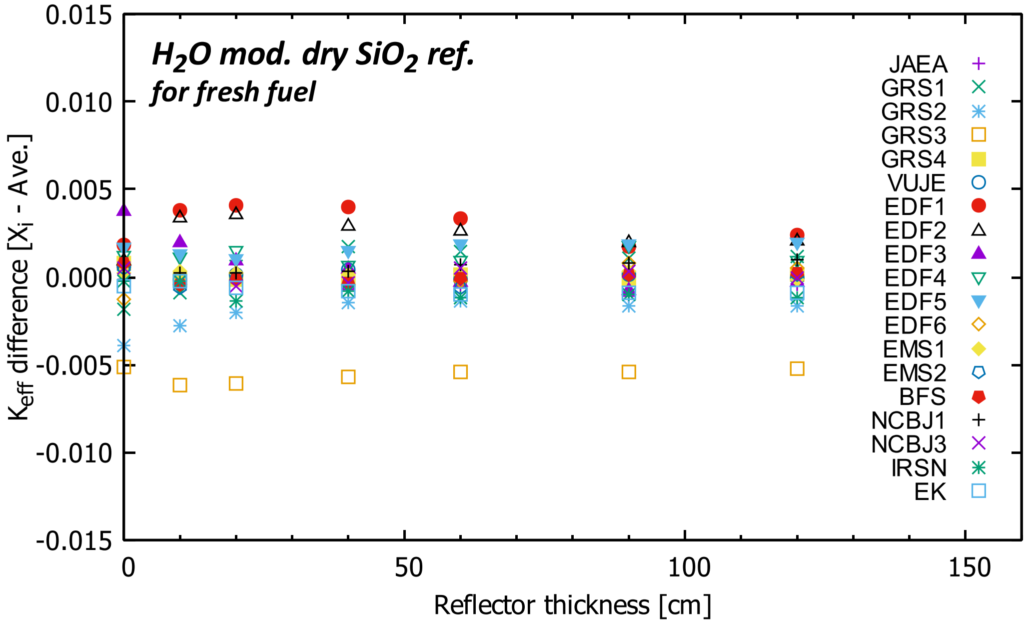


Figure A.24 Difference of k_{eff} of each participant from the average over all participants (H_2O moderator and wet SiO_2 reflector for fresh fuel case)

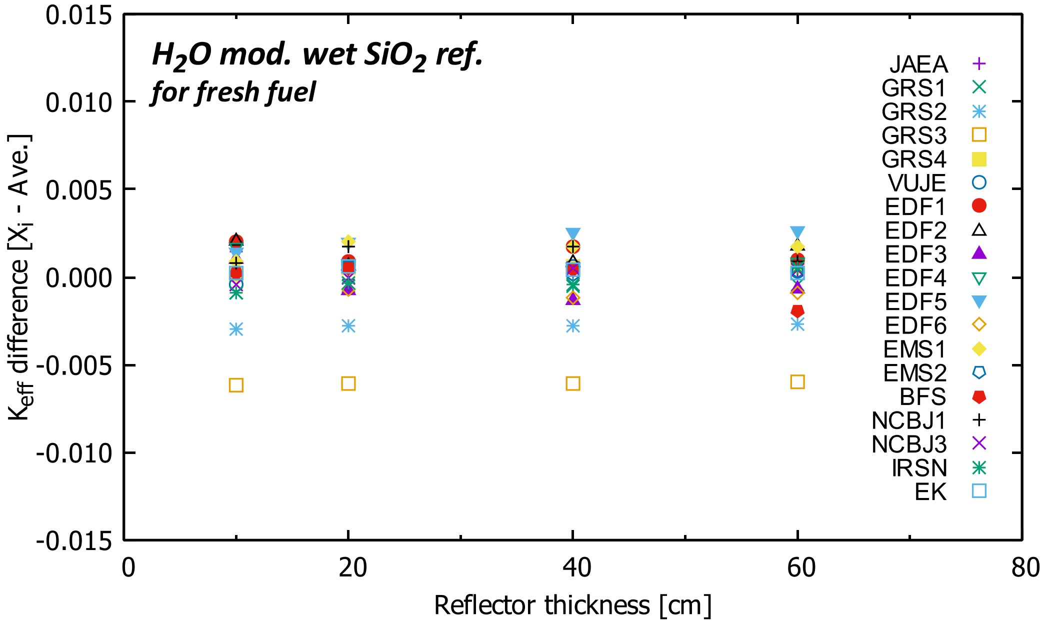


Figure A.25 Difference of k_{eff} of each participant from the average over all participants (H_2O moderator and H_2O reflector for fresh fuel case)

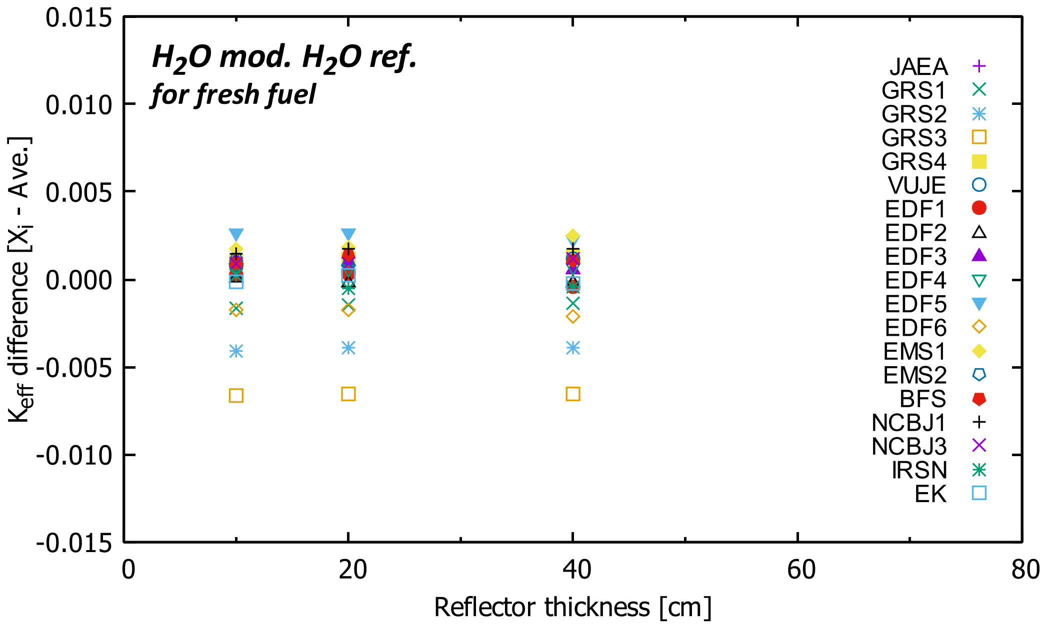


Figure A.26 Difference of k_{eff} of each participant from the average over all participants (wet SiO_2 moderator and wet SiO_2 reflector for fresh fuel case)

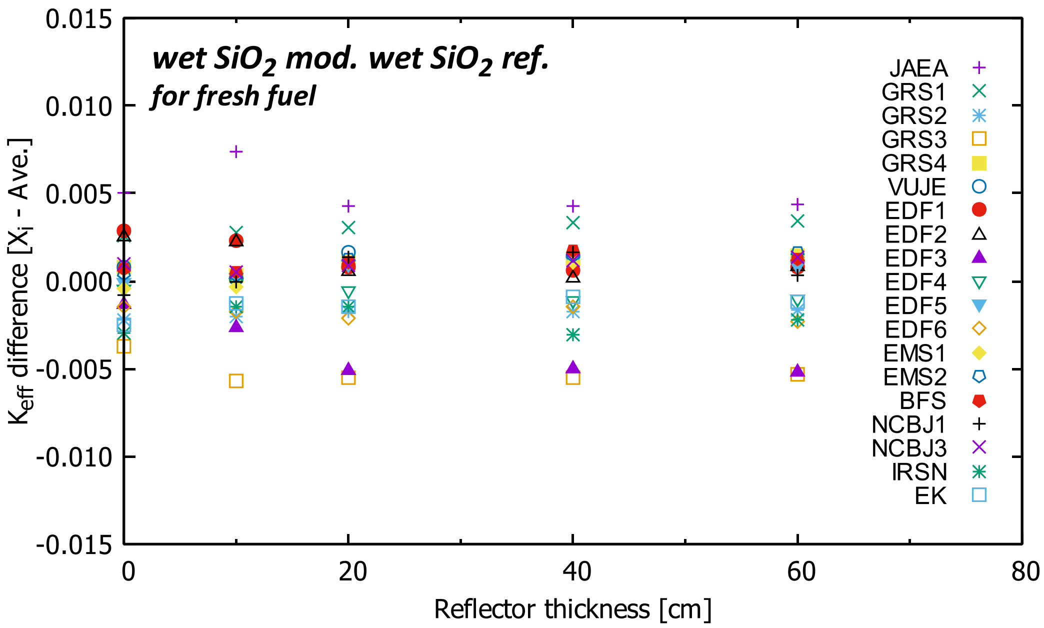


Figure A.27 Difference of k_{eff} of each participant from the average over all participants (30 GWd/t, after 0 year, H_2O moderator and dry SiO_2 reflector for used fuel case)

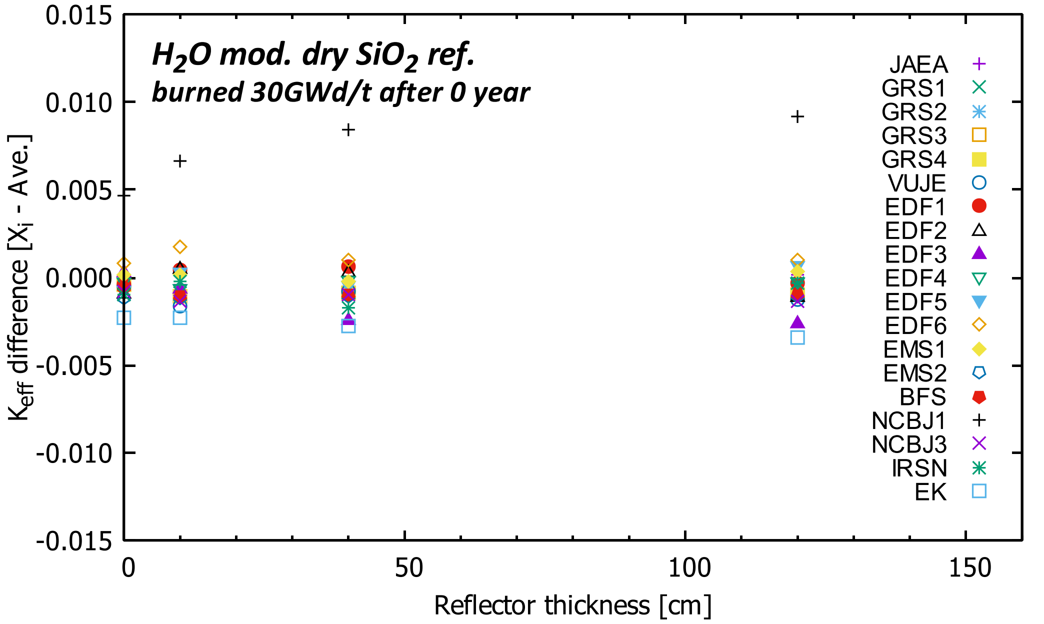


Figure A.28 Difference of k_{eff} of each participant from the average over all participants (30 GWd/t, after 0 year, H_2O moderator and wet SiO_2 reflector for used fuel case)

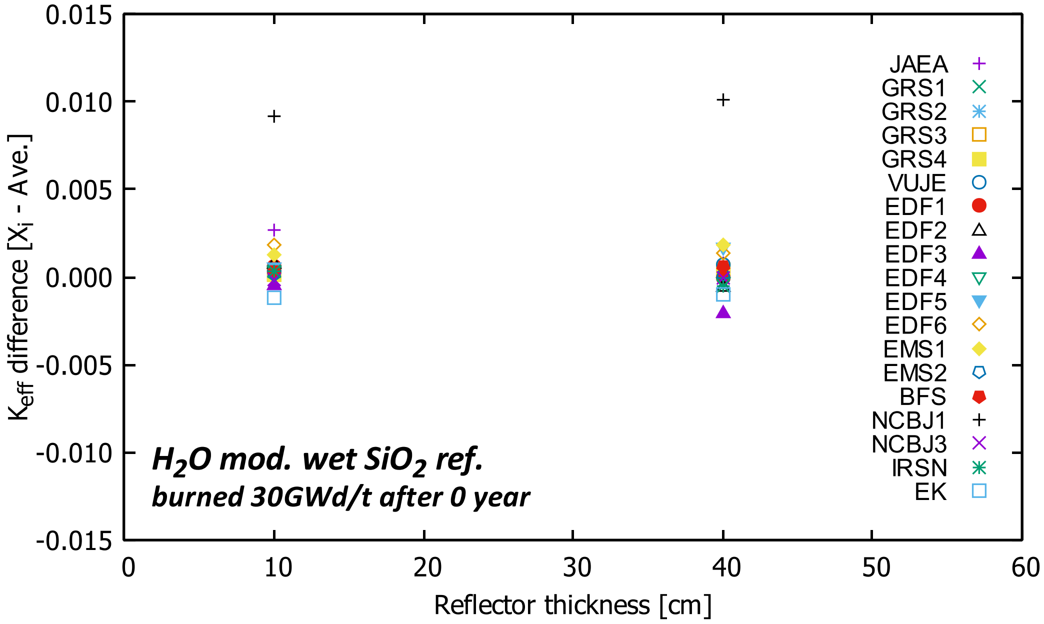


Figure A.29 Difference of k_{eff} of each participant from the average over all participants (30 GWd/t, after 0 year, H_2O moderator and H_2O reflector for used fuel case)

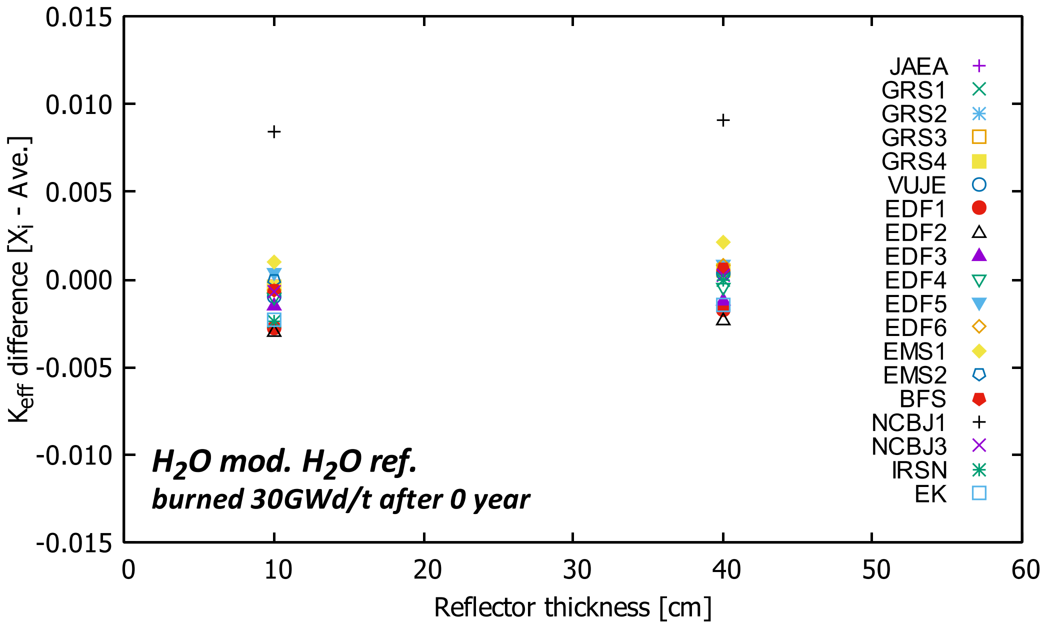


Figure A.30 Difference of k_{eff} of each participant from the average over all participants (30 GWd/t, after 30 000 year, H_2O moderator and dry SiO_2 reflector for used fuel case)

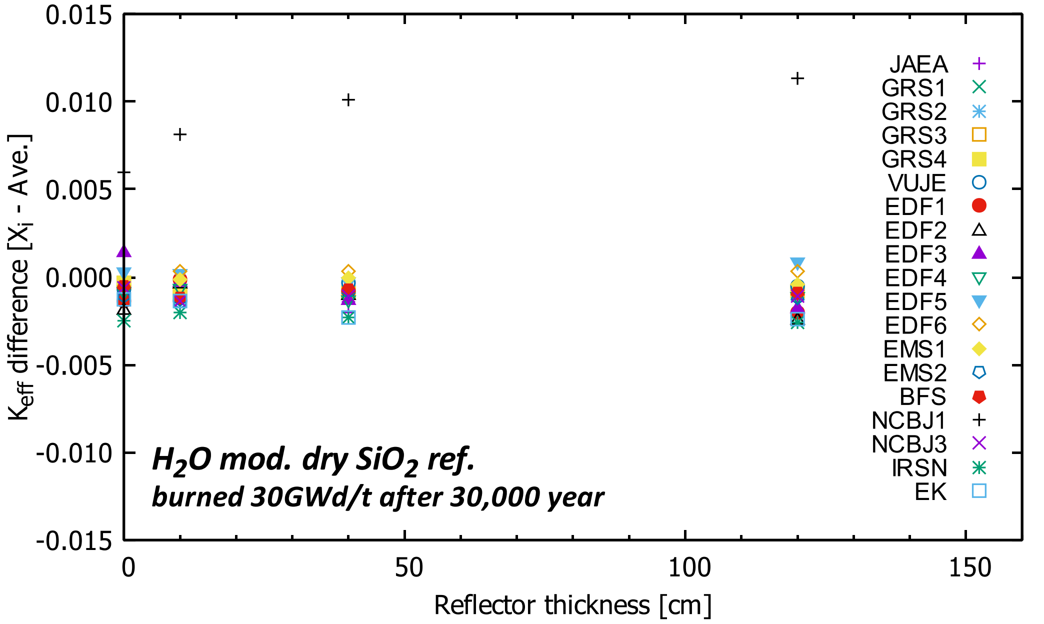


Figure A.31 Difference of k_{eff} of each participant from the average over all participants (30 GWd/t, after 30 000 year, H_2O moderator and wet SiO_2 reflector for used fuel case)

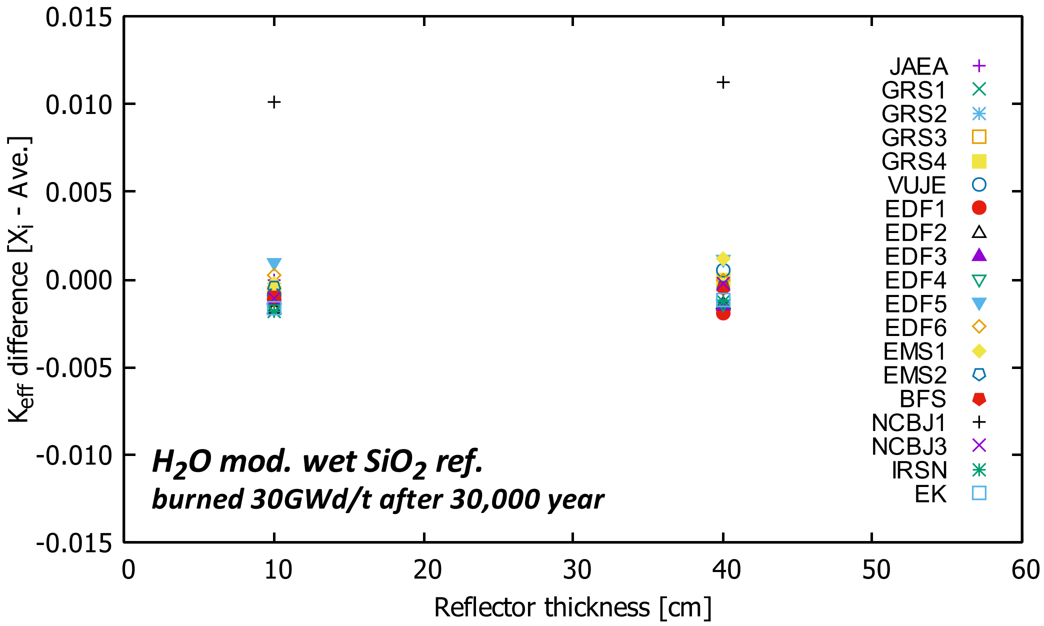


Figure A.32 Difference of k_{eff} of each participant from the average over all participants (30 GWd/t, after 30 000 year, H_2O moderator and H_2O reflector for used fuel case)

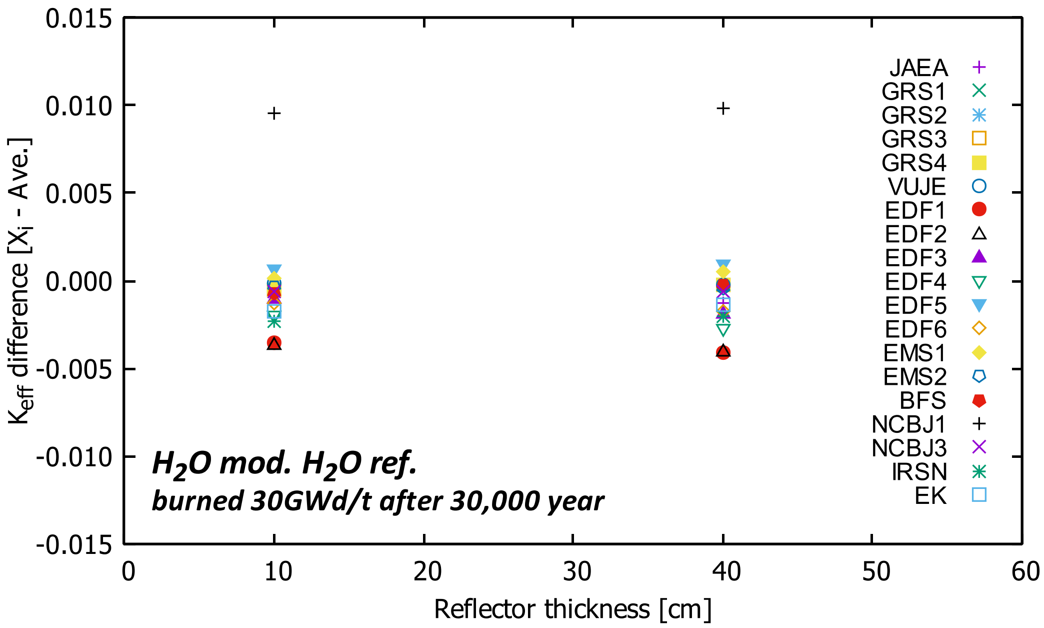


Figure A.33 Difference of k_{eff} of each participant from the average over all participants (30 GWd/t, after 20 million year, H_2O moderator and dry SiO_2 reflector for used fuel case)

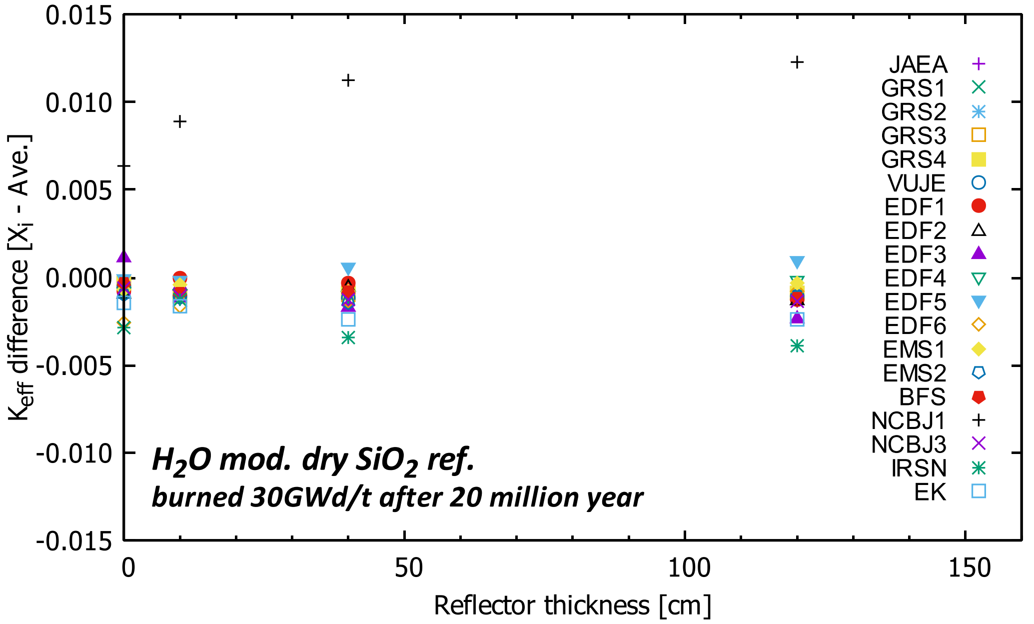


Figure A.34 Difference of k_{eff} of each participant from the average over all participants (30 GWd/t, after 20 million year, H_2O moderator and wet SiO_2 reflector for used fuel case)

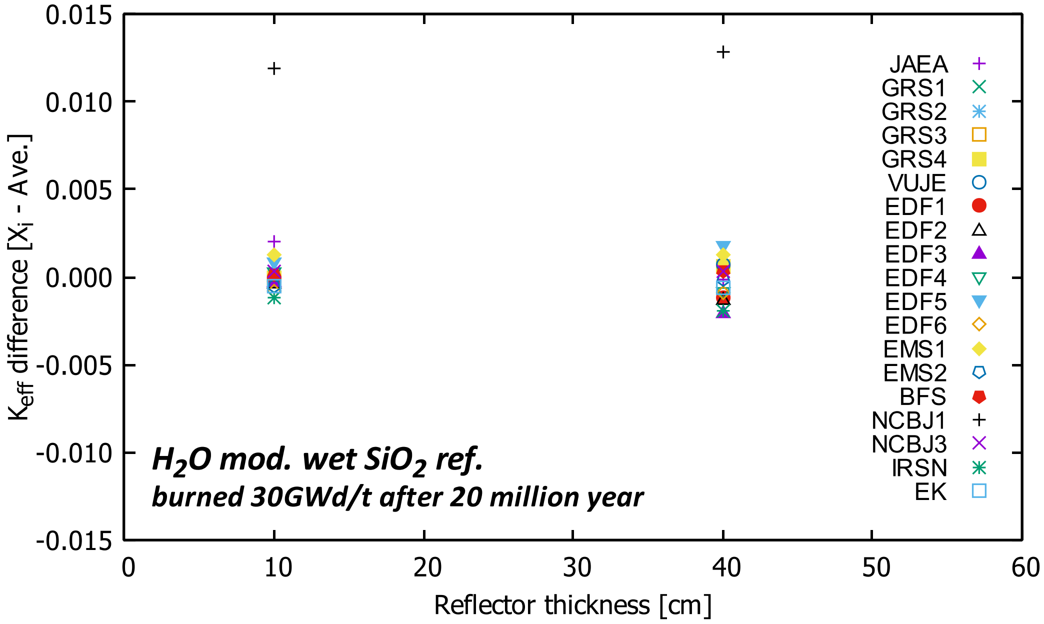


Figure A.35 Difference of k_{eff} of each participant from the average over all participants (30 GWd/t, after 20 million year, H_2O moderator and H_2O reflector for used fuel case)

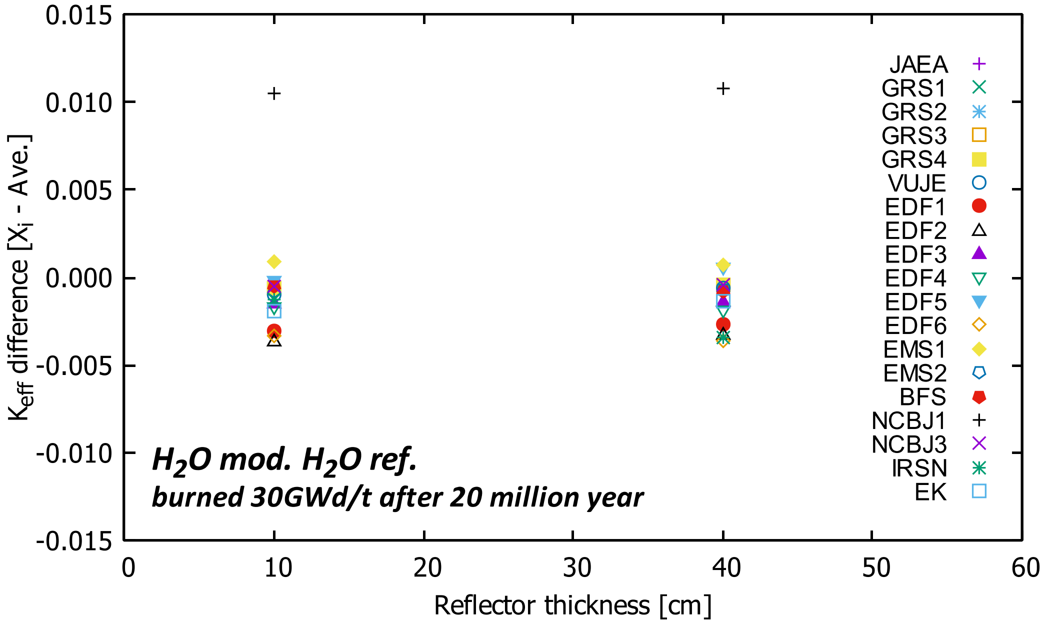


Figure A.36 Difference of k_{eff} of each participant from the average over all participants (45 GWd/t, after 0 year, H_2O moderator and dry SiO_2 reflector for used fuel case)

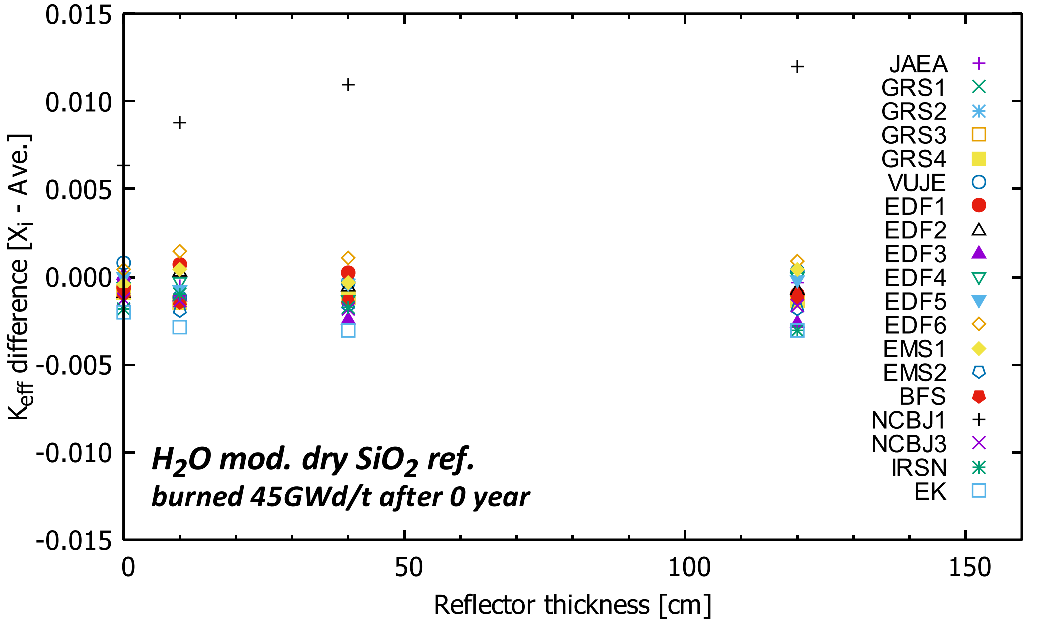


Figure A.37 Difference of k_{eff} of each participant from the average over all participants (45 GWd/t, after 0 year, H_2O moderator and wet SiO_2 reflector for used fuel case)

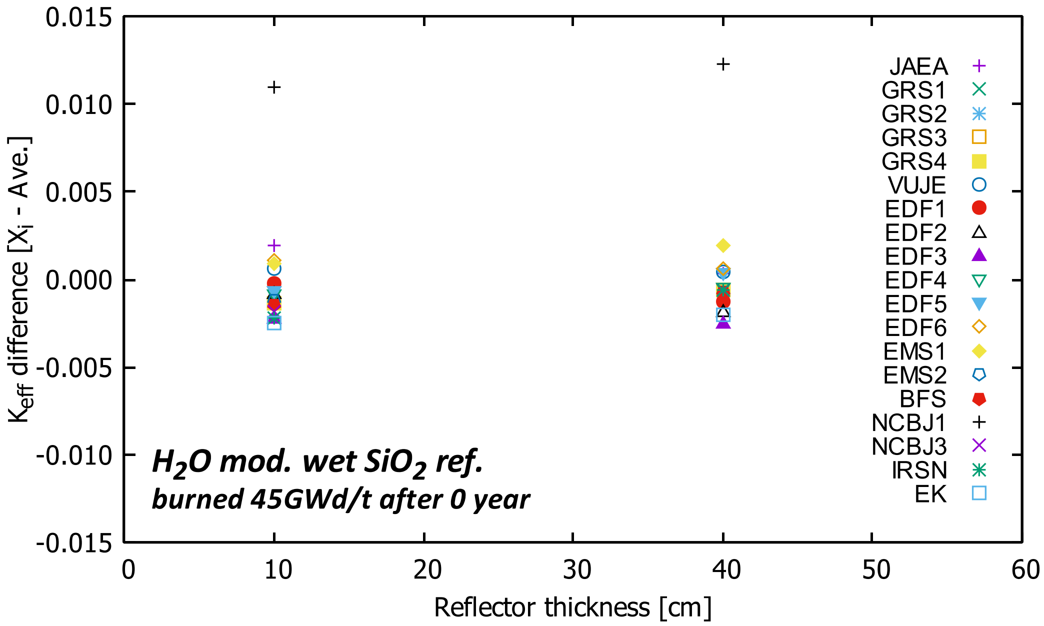


Figure A.38 Difference of k_{eff} of each participant from the average over all participants (45 GWd/t, after 0 year, H_2O moderator and H_2O reflector for used fuel case)

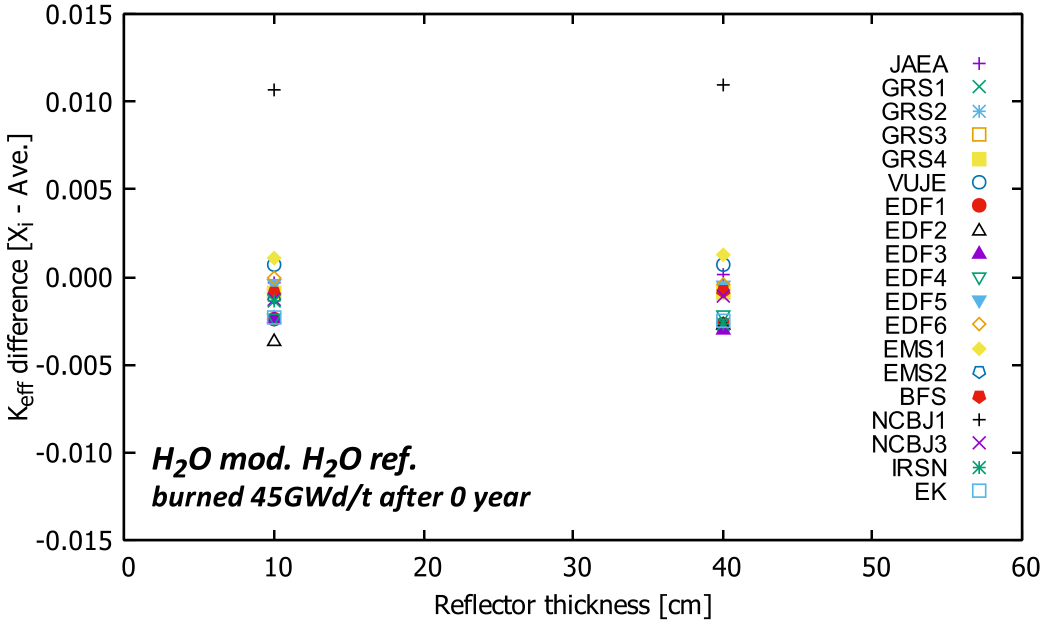


Figure A.39 Difference of k_{eff} of each participant from the average over all participants (45 GWd/t, after 30 000 year, H_2O moderator and dry SiO_2 reflector for used fuel case)

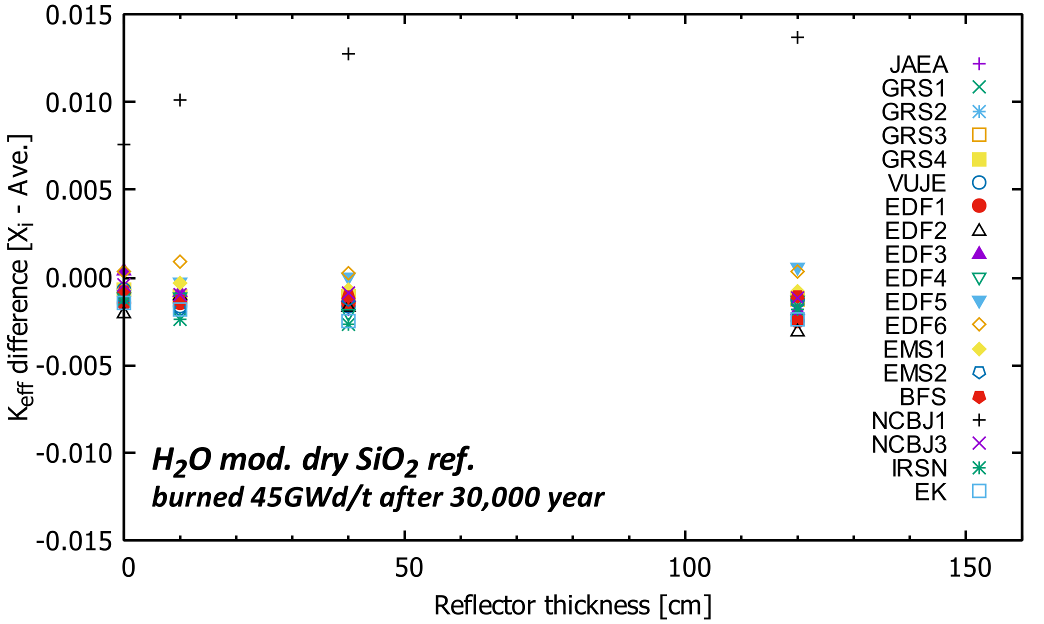


Figure A.40 Difference of k_{eff} of each participant from the average over all participants (45 GWd/t, after 30 000 year, H_2O moderator and wet SiO_2 reflector for used fuel case)

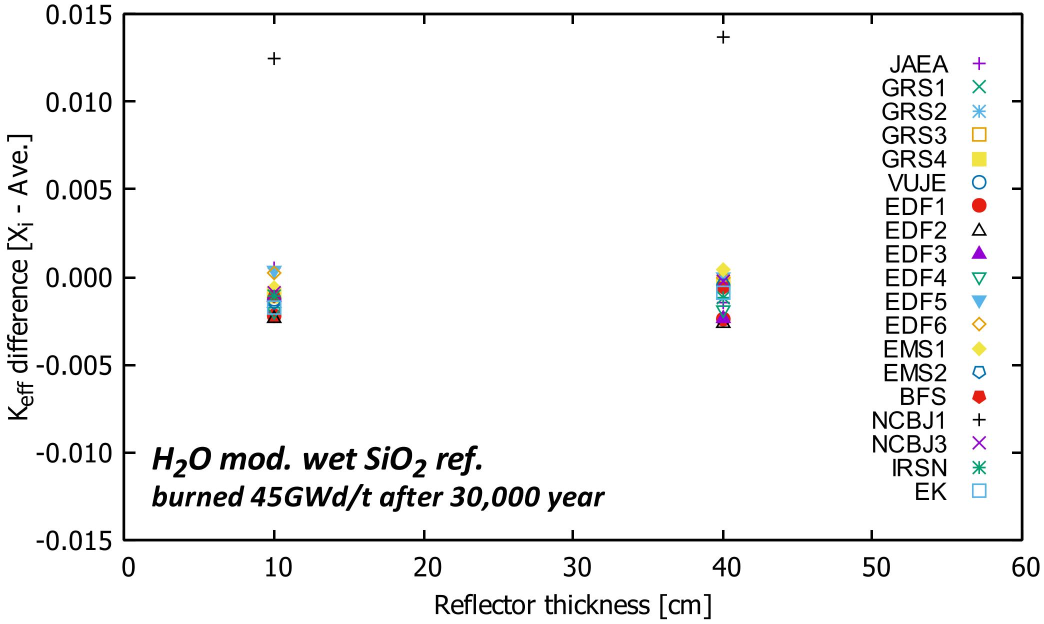


Figure A.41 Difference of k_{eff} of each participant from the average over all participants (45 GWd/t, after 30 000 year, H_2O moderator and H_2O reflector for used fuel case)

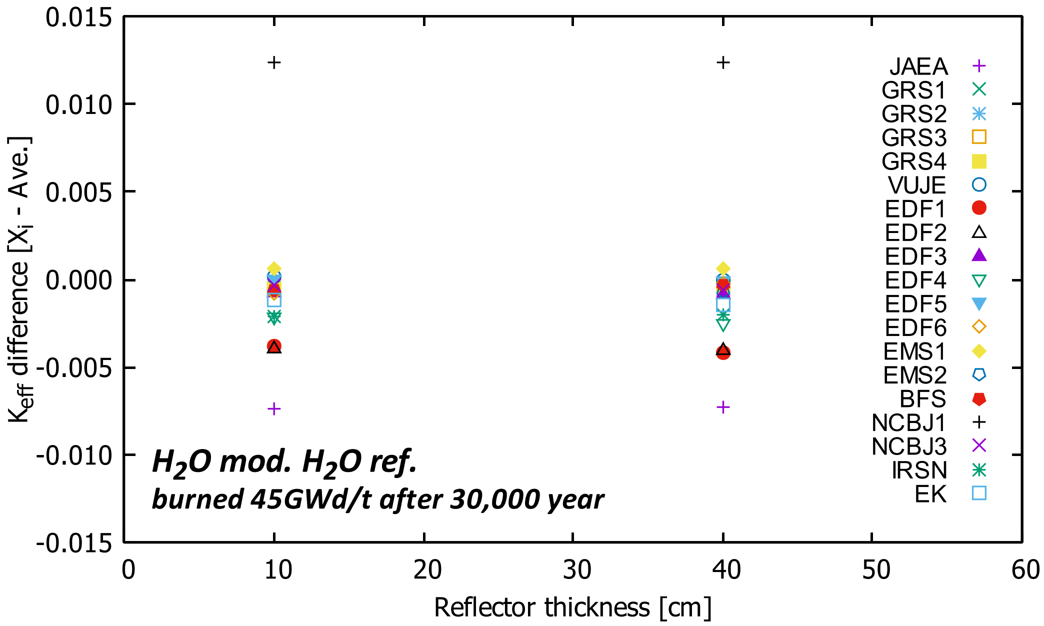


Figure A.42 Difference of k_{eff} of each participant from the average over all participants (45 GWd/t, after 20 million year, H_2O moderator and dry SiO_2 reflector for used fuel case)

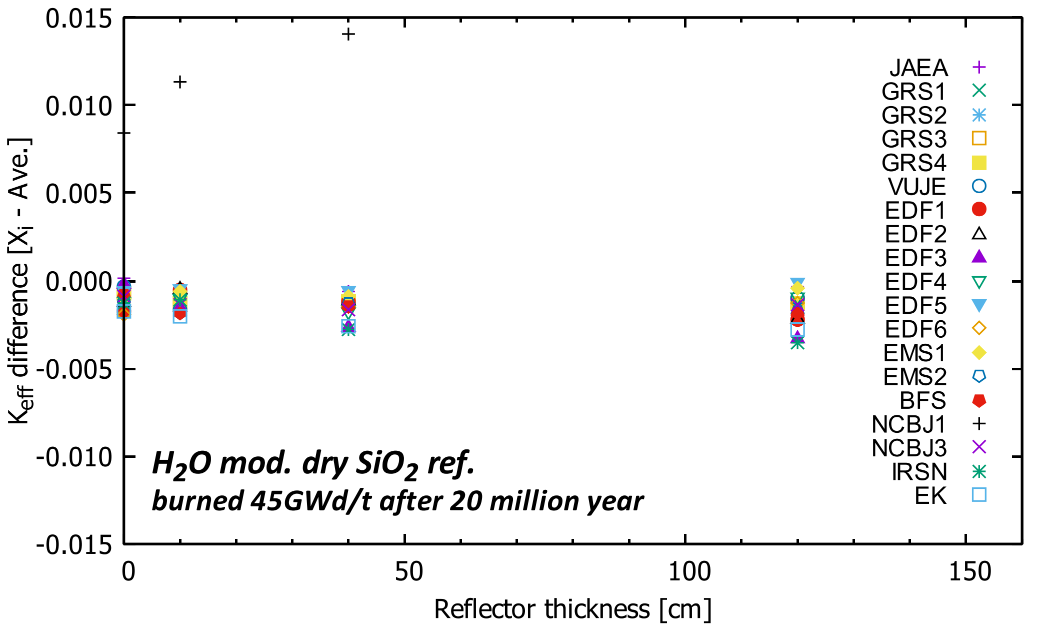


Figure A.43 Difference of k_{eff} of each participant from the average over all participants (45 GWd/t, after 20 million year, H_2O moderator and wet SiO_2 reflector for used fuel case)

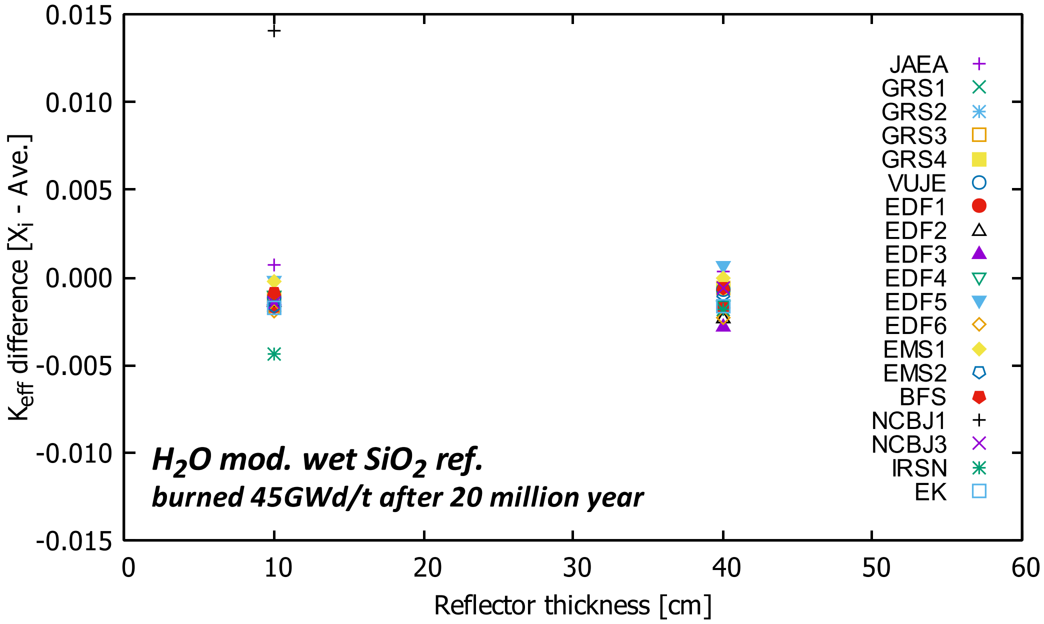


Figure A.44 Difference of k_{eff} of each participant from the average over all participants (45 GWd/t, after 20 million year, H_2O moderator and H_2O reflector for used fuel case)

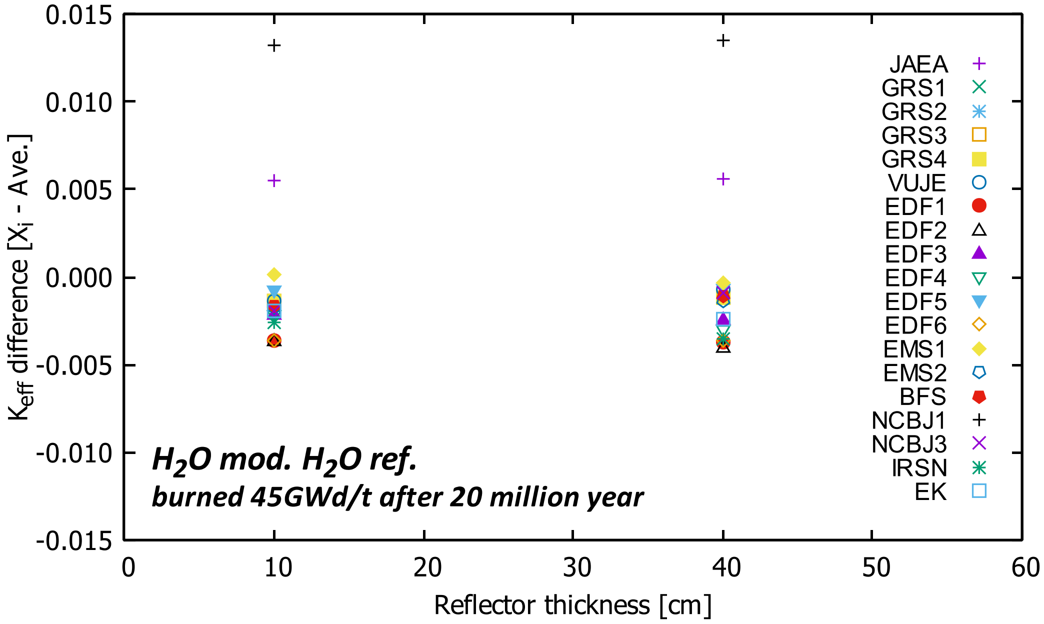


Figure A.45 R_{eff} against reflector thickness (H_2O moderator and dry SiO_2 reflector for fresh fuel case)

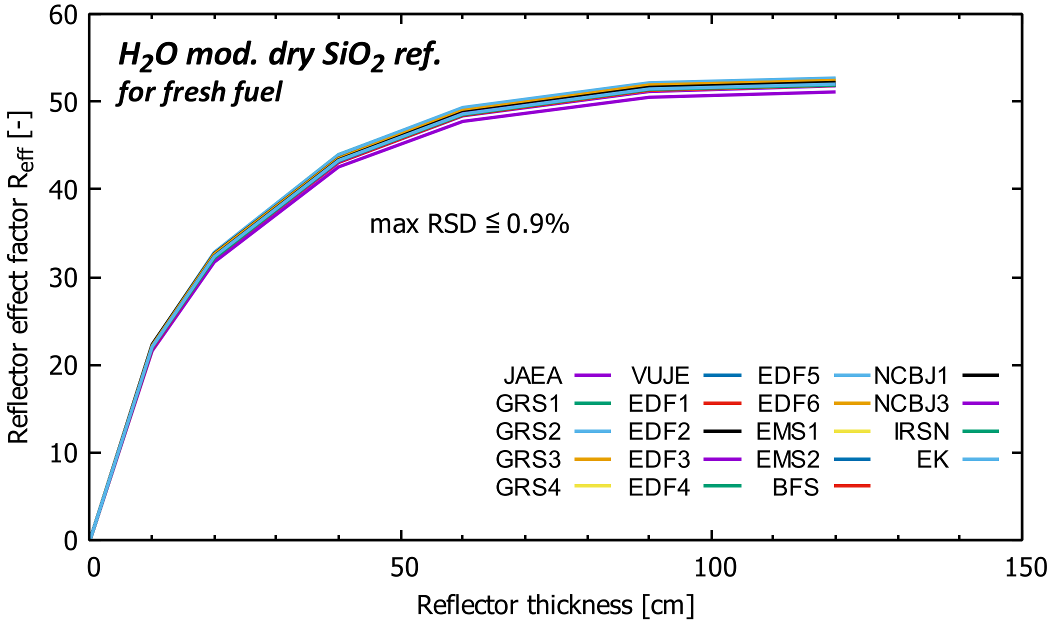


Figure A.46 R_{eff} against reflector thickness (H_2O moderator and wet SiO_2 reflector for fresh fuel case)

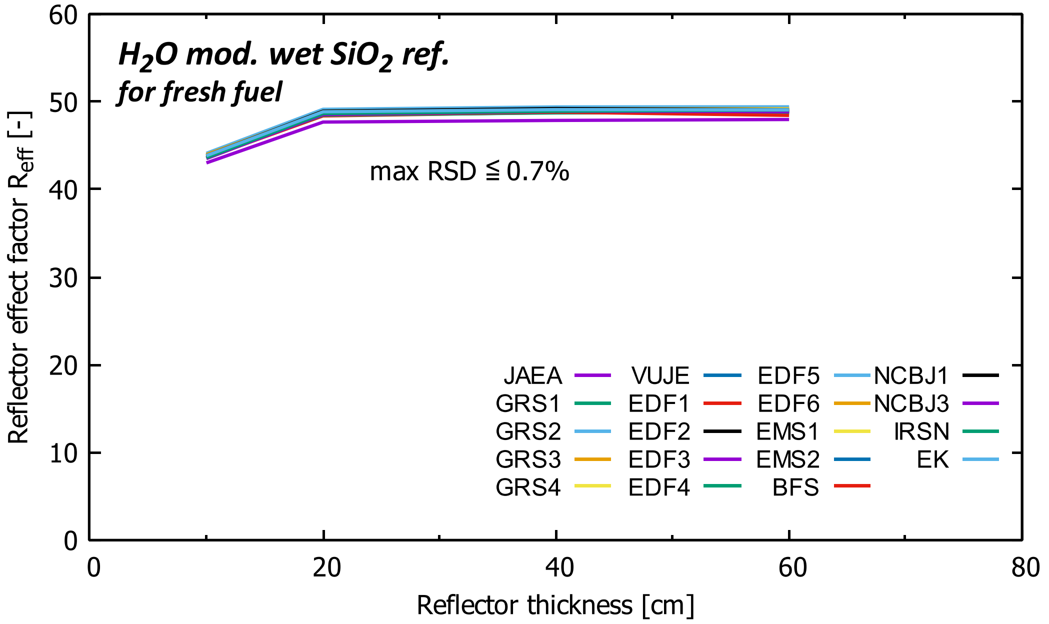


Figure A.47 R_{eff} against reflector thickness (H_2O moderator and H_2O reflector for fresh fuel case)

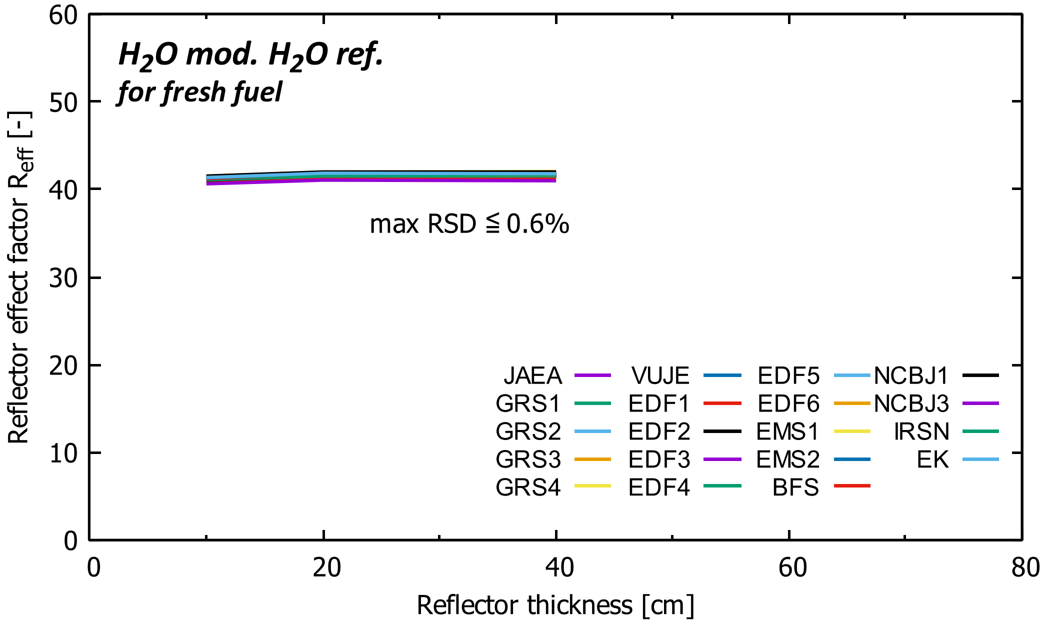


Figure A.48 R_{eff} against reflector thickness (wet SiO_2 moderator and wet SiO_2 reflector for fresh fuel case)

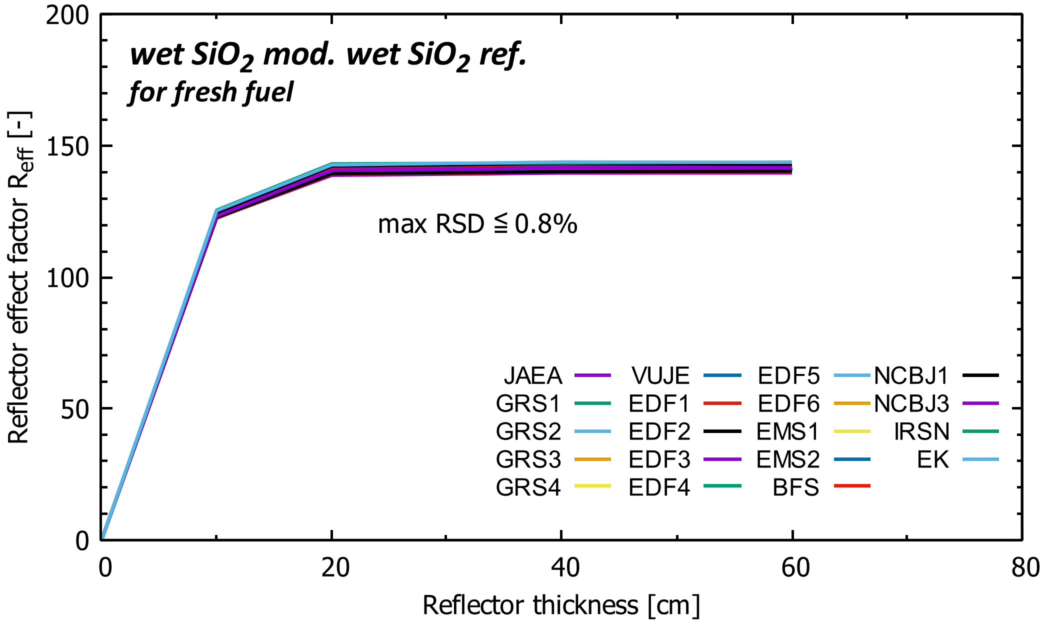


Figure A.49 R_{eff} against reflector thickness (30 GWd/t, after 0 year, H_2O moderator and dry SiO_2 reflector for used fuel case)

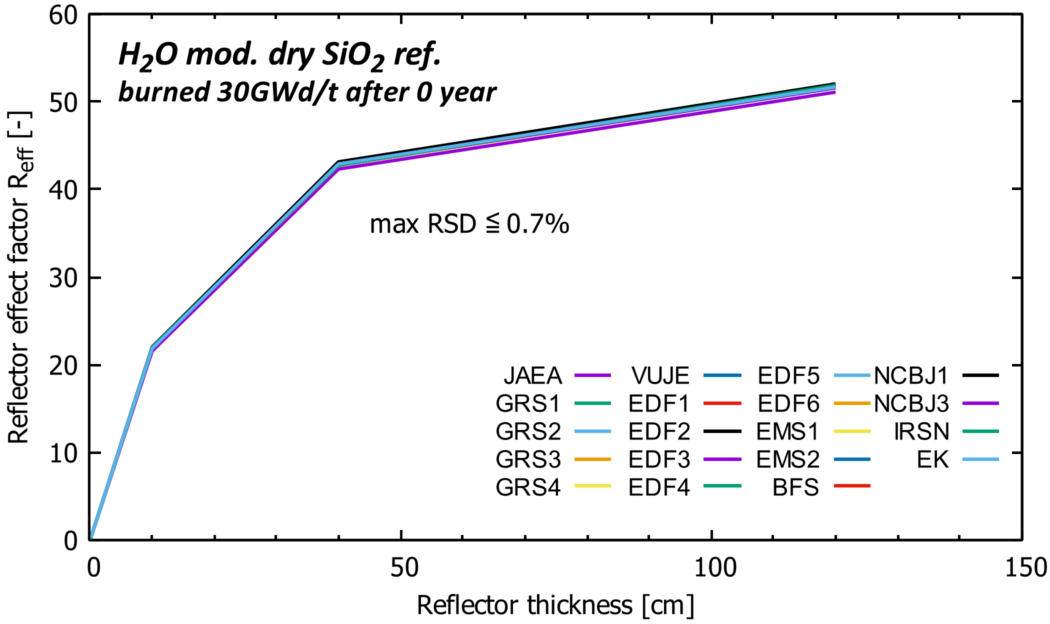


Figure A.50 R_{eff} against reflector thickness (30 GWd/t, after 0 year, H_2O moderator and wet SiO_2 reflector for used fuel case)

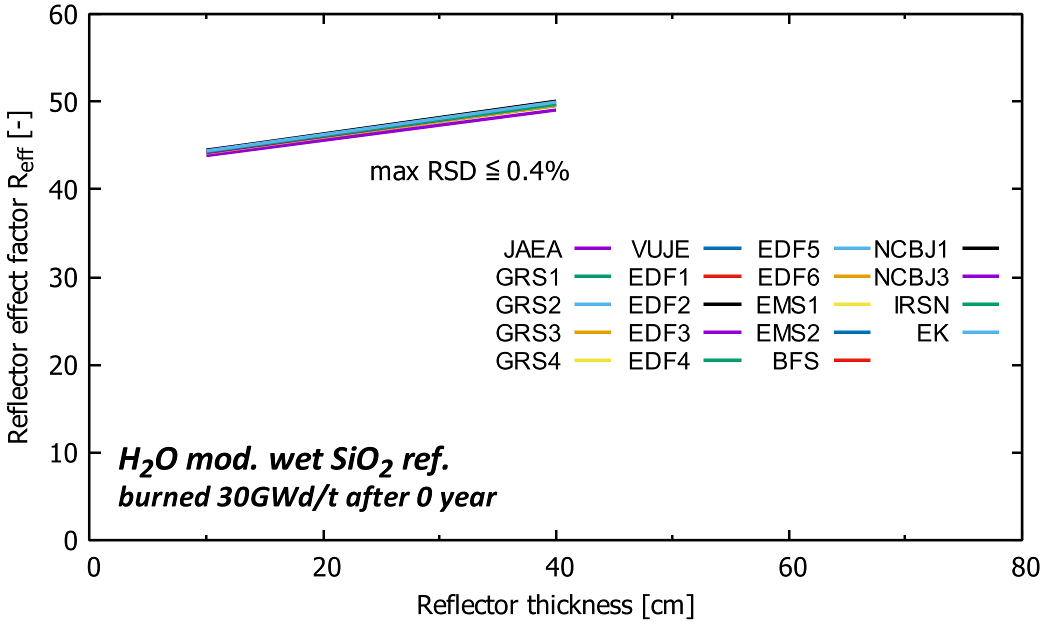


Figure A.51 R_{eff} against reflector thickness (30 GWd/t, after 0 year, H_2O moderator and H_2O reflector for used fuel case)

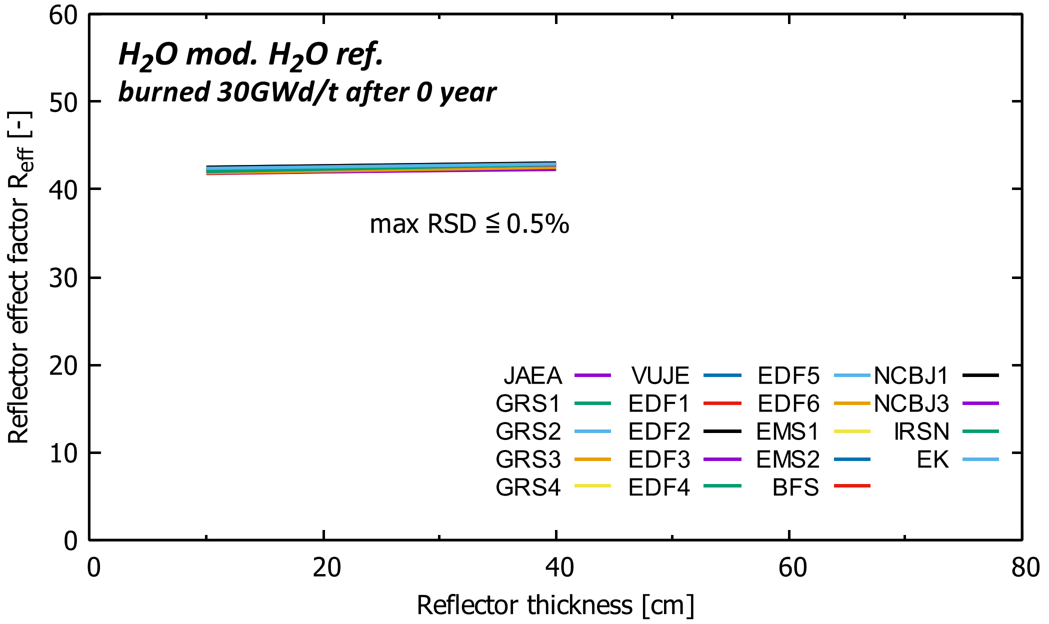


Figure A.52 R_{eff} against reflector thickness (30 GWd/t, after 30 000 year, H_2O moderator and dry SiO_2 reflector for used fuel case)

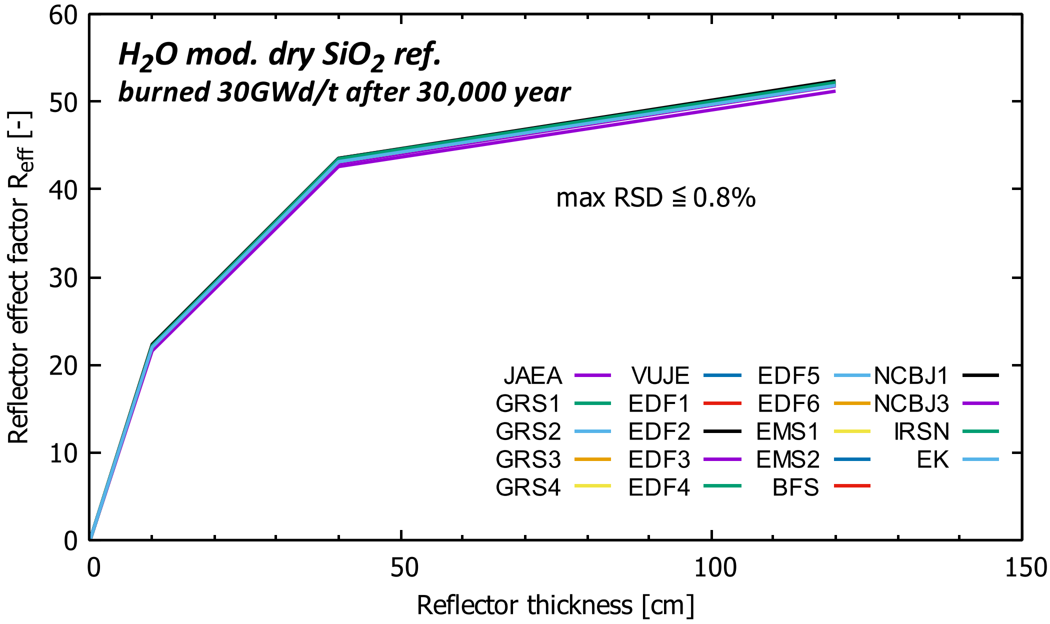


Figure A.53 R_{eff} against reflector thickness (30 GWd/t, after 30 000 year, H_2O moderator and wet SiO_2 reflector for used fuel case)

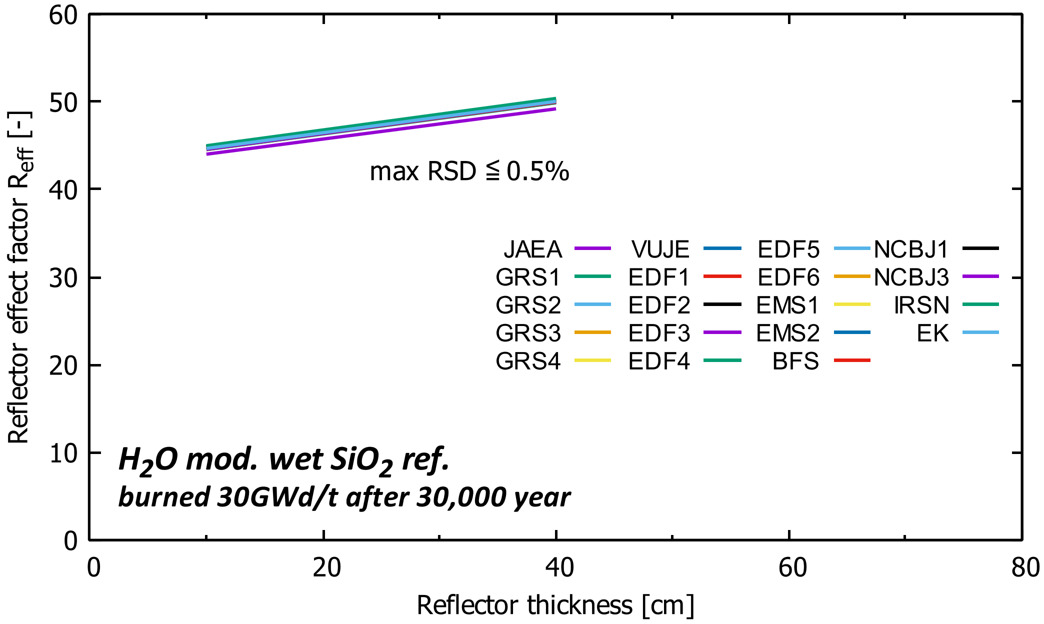


Figure A.54 R_{eff} against reflector thickness (30 GWd/t, after 30 000 year, H_2O moderator and H_2O reflector for used fuel case)

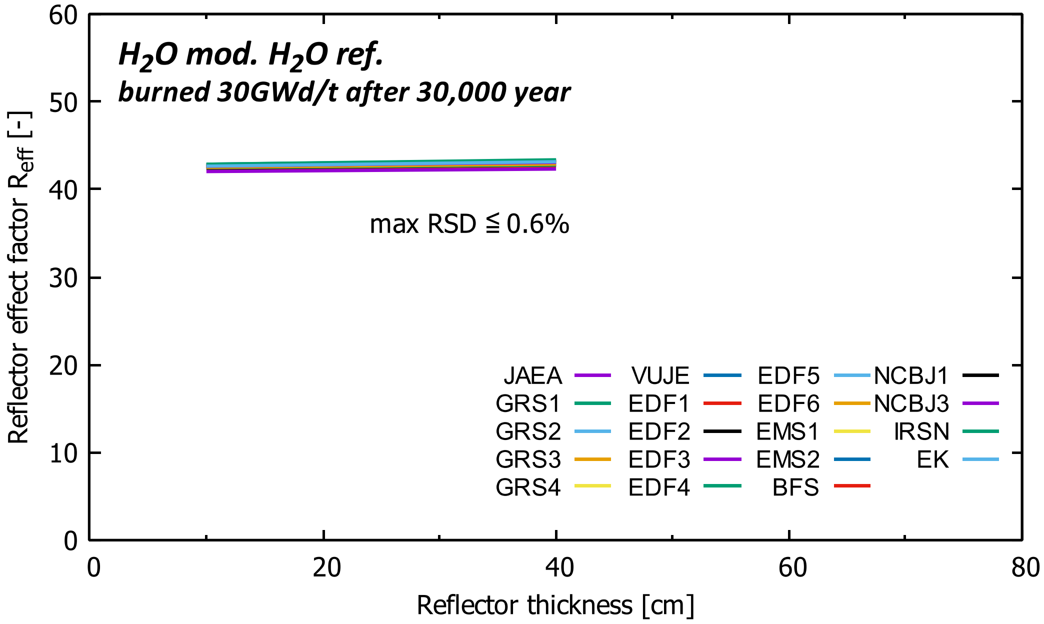


Figure A.55 R_{eff} against reflector thickness (30 GWd/t, after 20 million year, H_2O moderator and dry SiO_2 reflector for used fuel case)

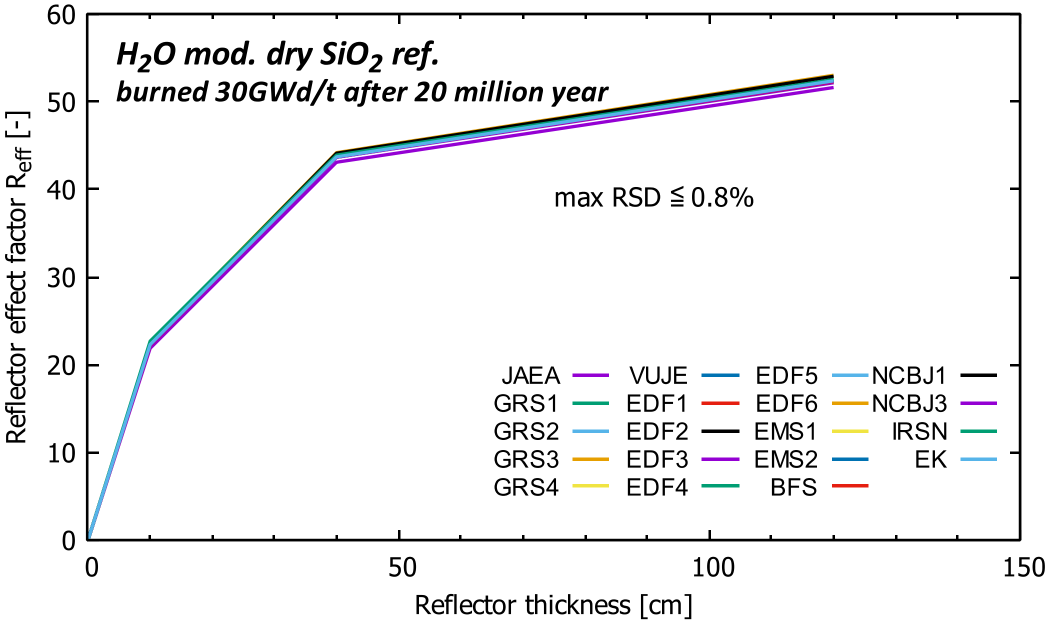


Figure A.56 R_{eff} against reflector thickness (30 GWd/t, after 20 million year, H_2O moderator and wet SiO_2 reflector for used fuel case)

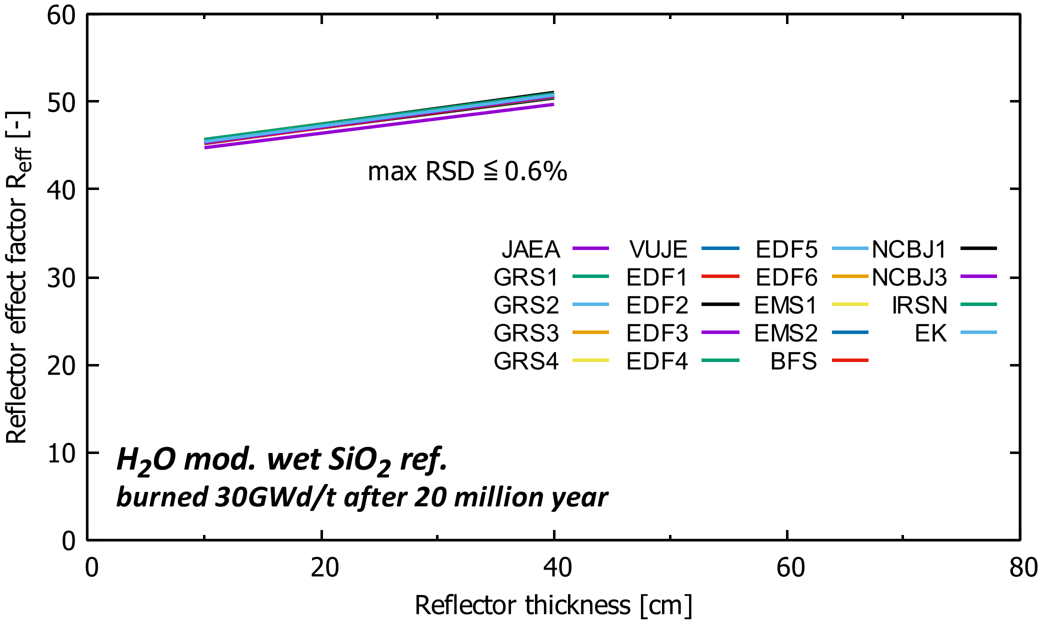


Figure A.57 R_{eff} against reflector thickness (30 GWd/t, after 20 million year, H_2O moderator and H_2O reflector for used fuel case)

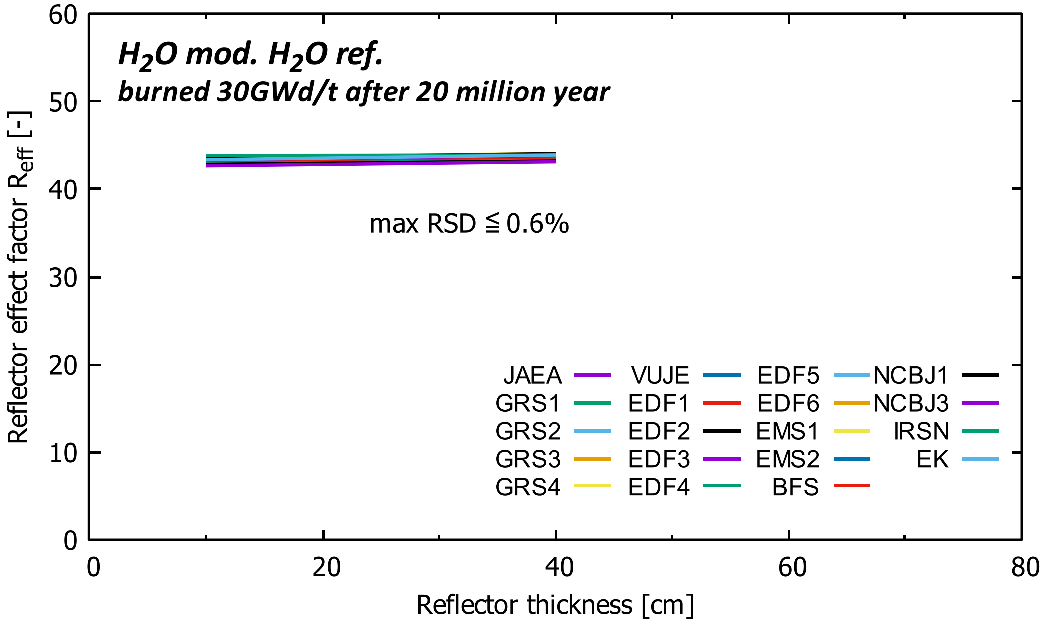


Figure A.58 R_{eff} against reflector thickness (45 GWd/t, after 0 year, H_2O moderator and dry SiO_2 reflector for used fuel case)

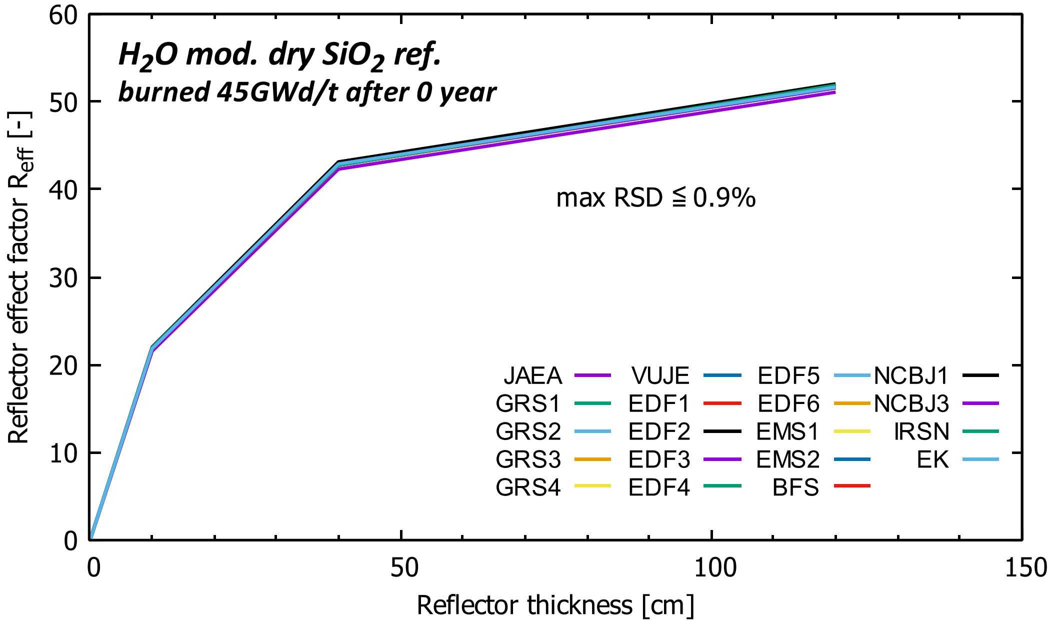


Figure A.59 R_{eff} against reflector thickness (45 GWd/t, after 0 year, H_2O moderator and wet SiO_2 reflector for used fuel case)

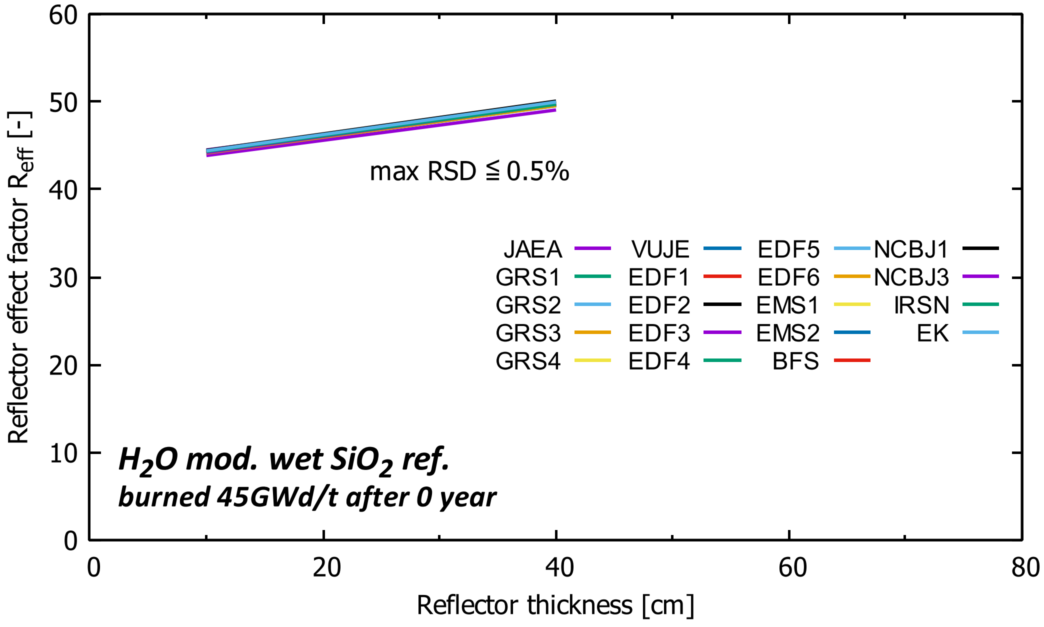


Figure A.60 R_{eff} against reflector thickness (45 GWd/t, after 0 year, H_2O moderator and H_2O reflector for used fuel case)

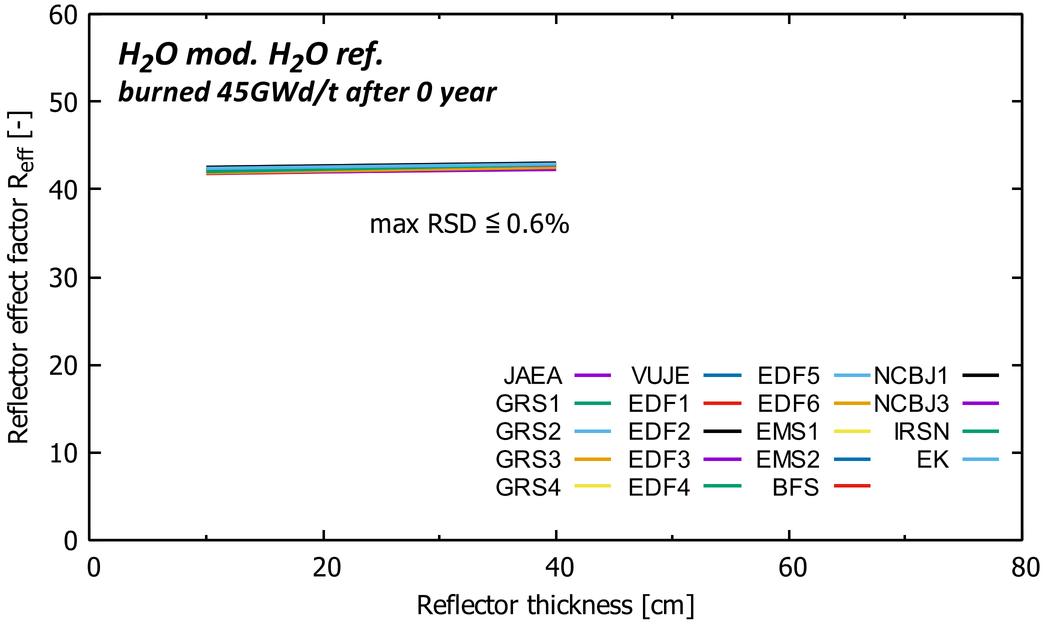


Figure A.61 R_{eff} against reflector thickness (45 GWd/t, after 30 000 year, H_2O moderator and dry SiO_2 reflector for used fuel case)

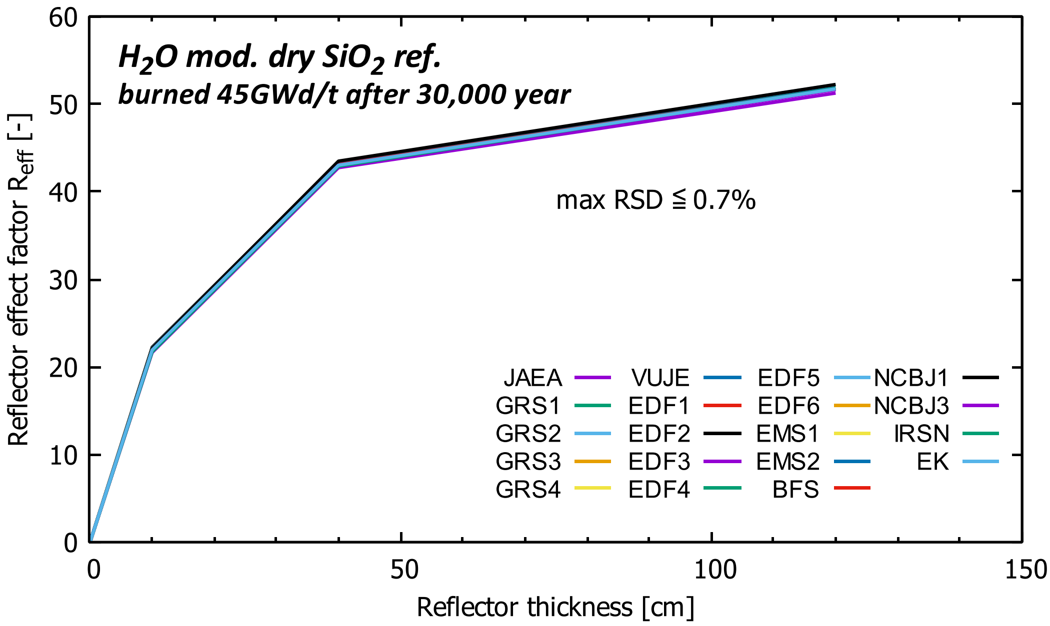


Figure A.62 R_{eff} against reflector thickness (45 GWd/t, after 30 000 year, H_2O moderator and wet SiO_2 reflector for used fuel case)

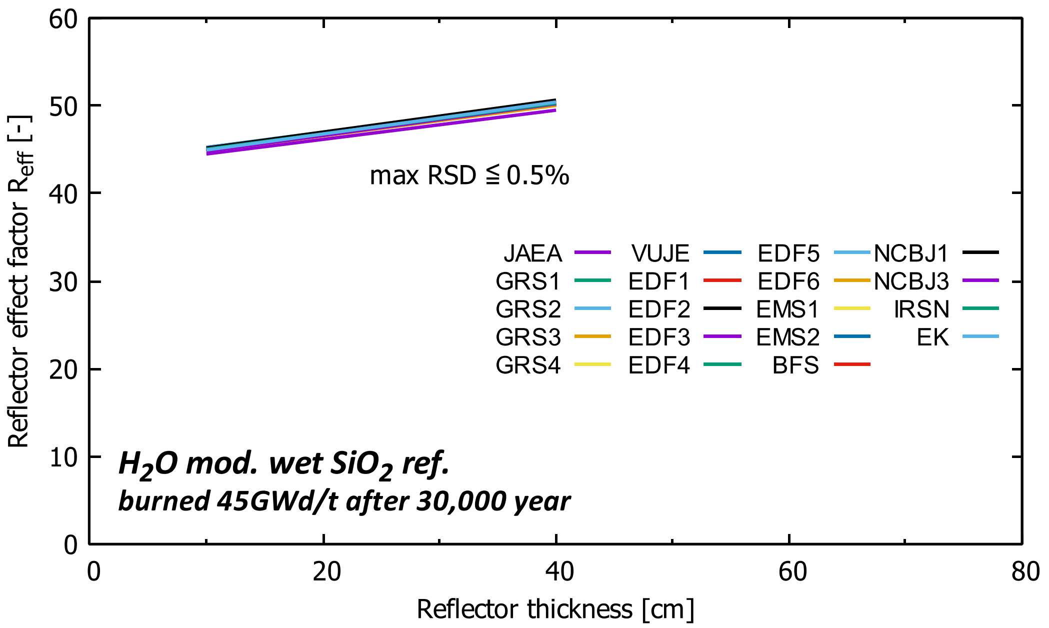


Figure A.63 R_{eff} against reflector thickness (45 GWd/t, after 30 000 year, H_2O moderator and H_2O reflector for used fuel case)

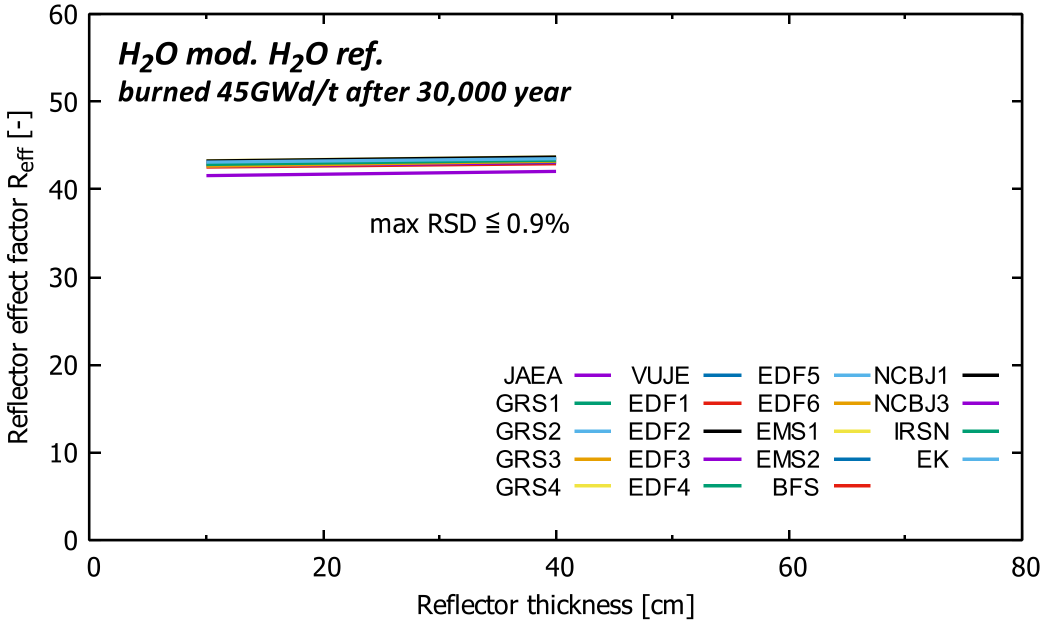


Figure A.64 R_{eff} against reflector thickness (45 GWd/t, after 20 million year, H_2O moderator and dry SiO_2 reflector for used fuel case)

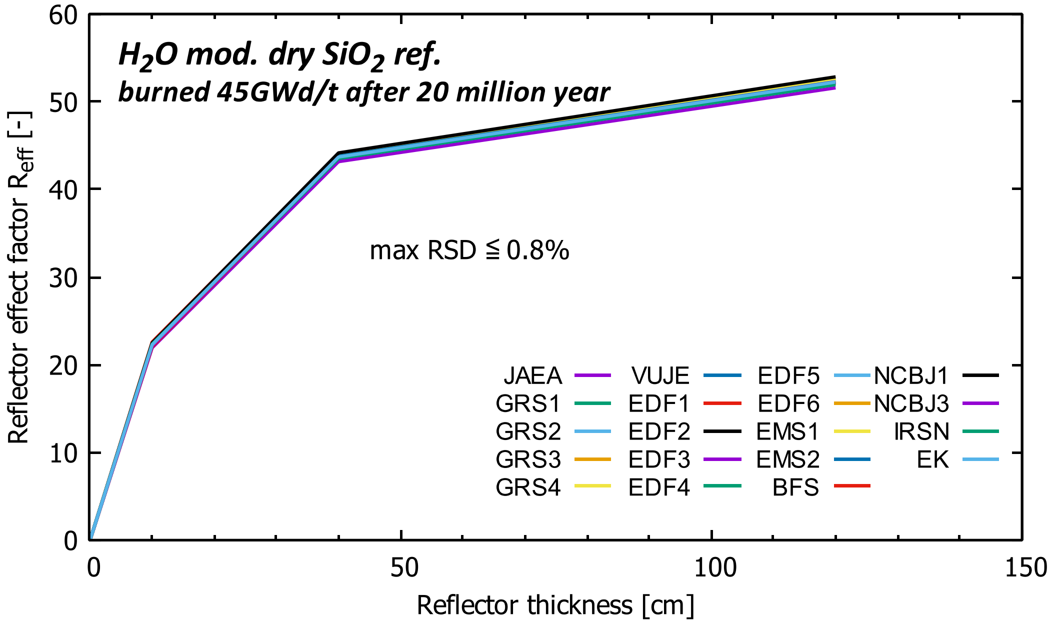


Figure A.65 R_{eff} against reflector thickness (45 GWd/t, after 20 million year, H_2O moderator and wet SiO_2 reflector for used fuel case)

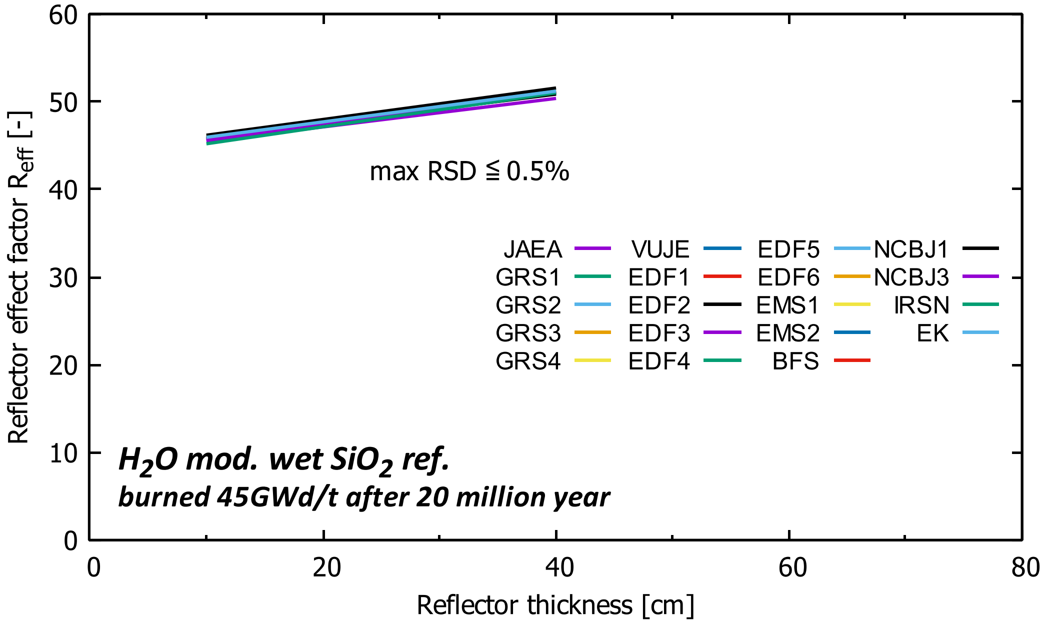


Figure A.66 R_{eff} against reflector thickness (45 GWd/t, after 20 million year, H_2O moderator and H_2O reflector for used fuel case)

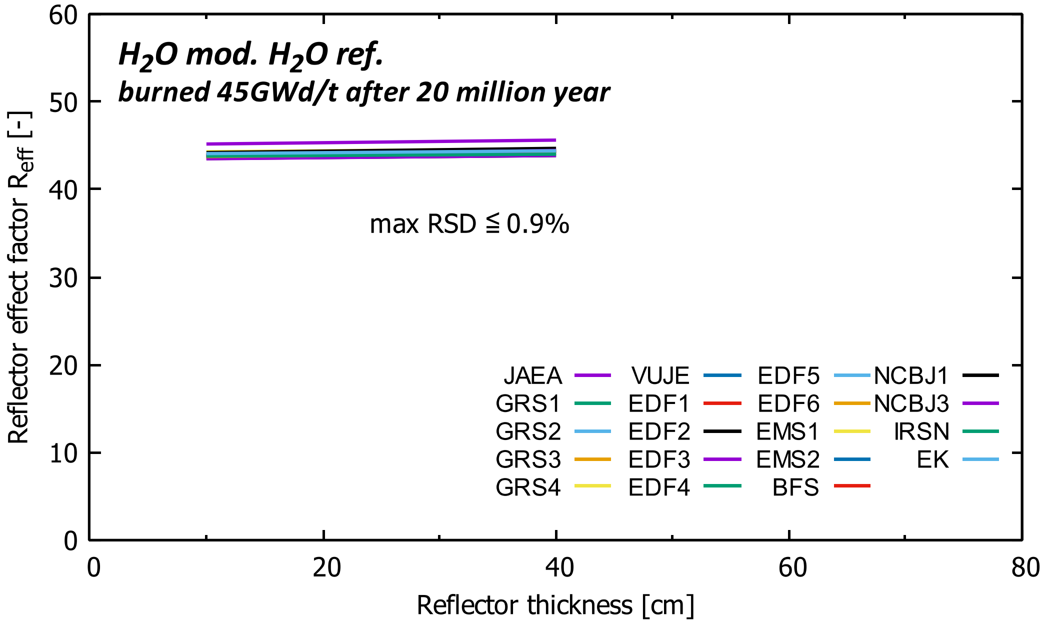


Figure A.67 Reaction rate of [16]O scattering against reflector thickness (H_2O moderator and dry SiO_2 reflector for fresh fuel case)

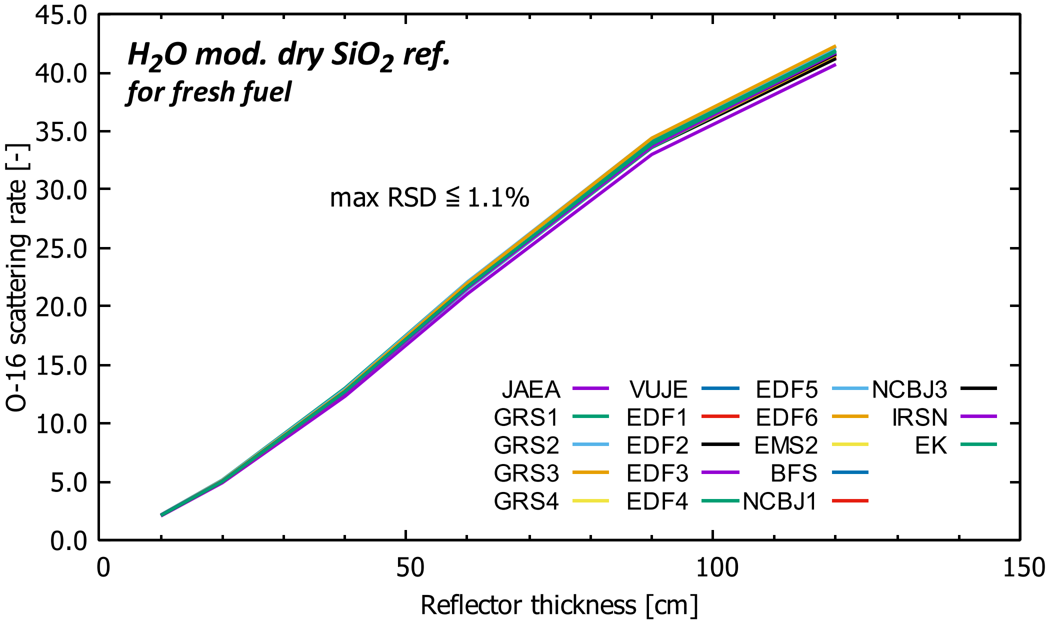


Figure A.68 Reaction rate of [16]O scattering against reflector thickness (H_2O moderator and wet SiO_2 reflector for fresh fuel case)

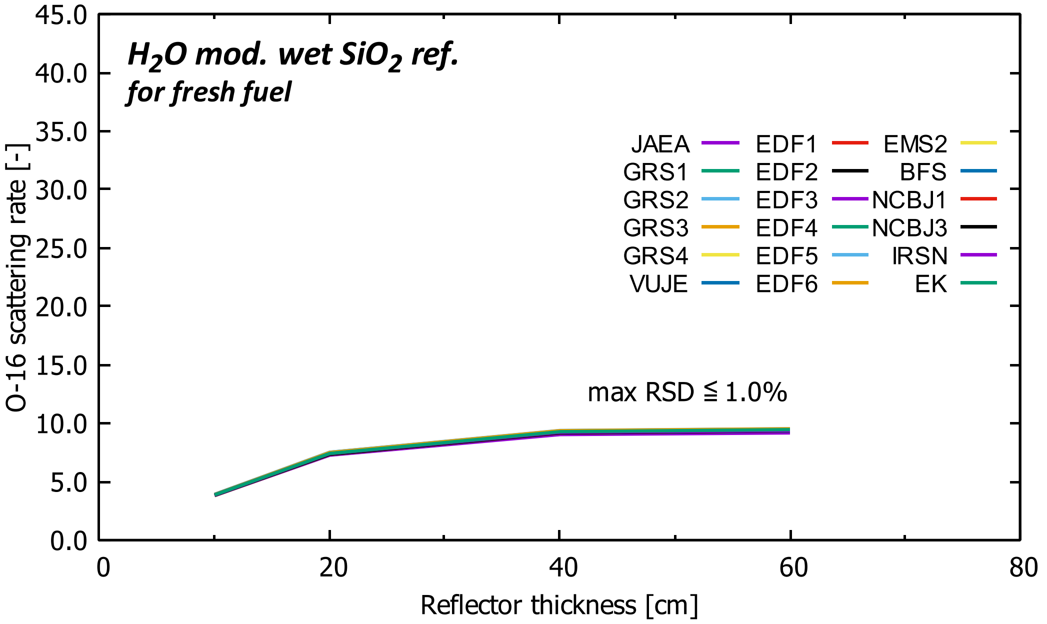


Figure A.69 Reaction rate of ^{16}O scattering against reflector thickness (H$_2$O moderator and H$_2$O reflector for fresh fuel case)

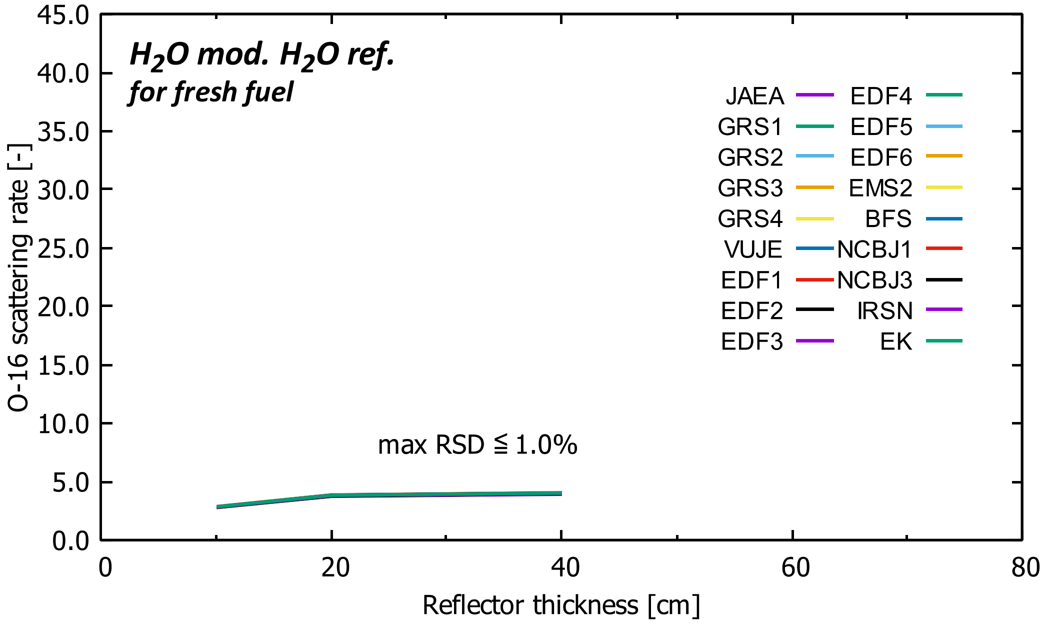


Figure A.70 Reaction rate of ^{28}Si scattering against reflector thickness (H$_2$O moderator and wet SiO$_2$ reflector for fresh fuel case)

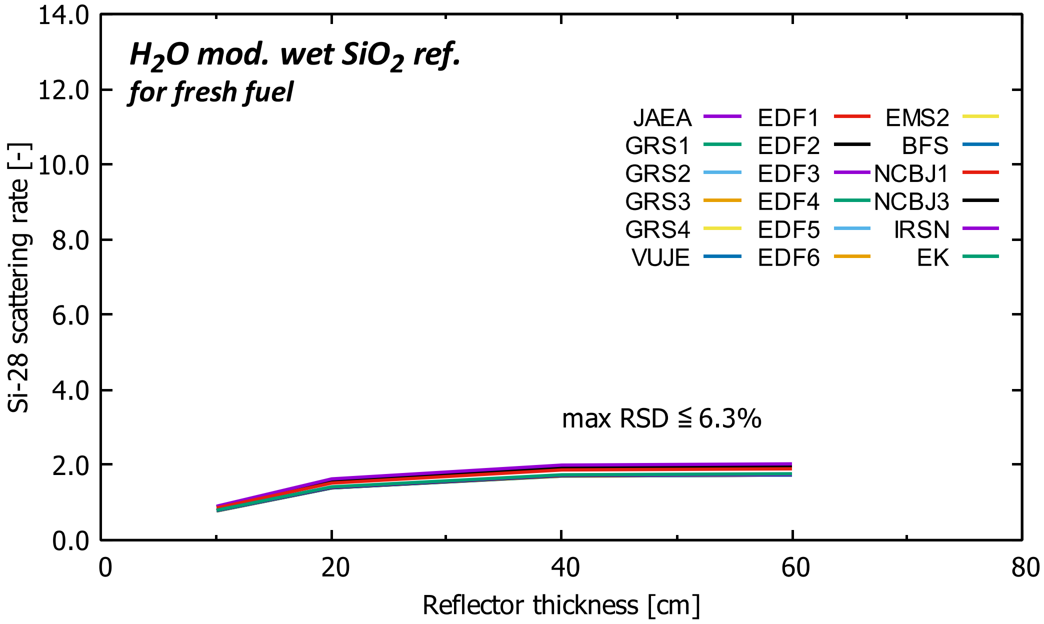


Figure A.71 Reaction rate of ^{28}Si scattering against reflector thickness (wet SiO_2 moderator and wet SiO_2 reflector for fresh fuel case)

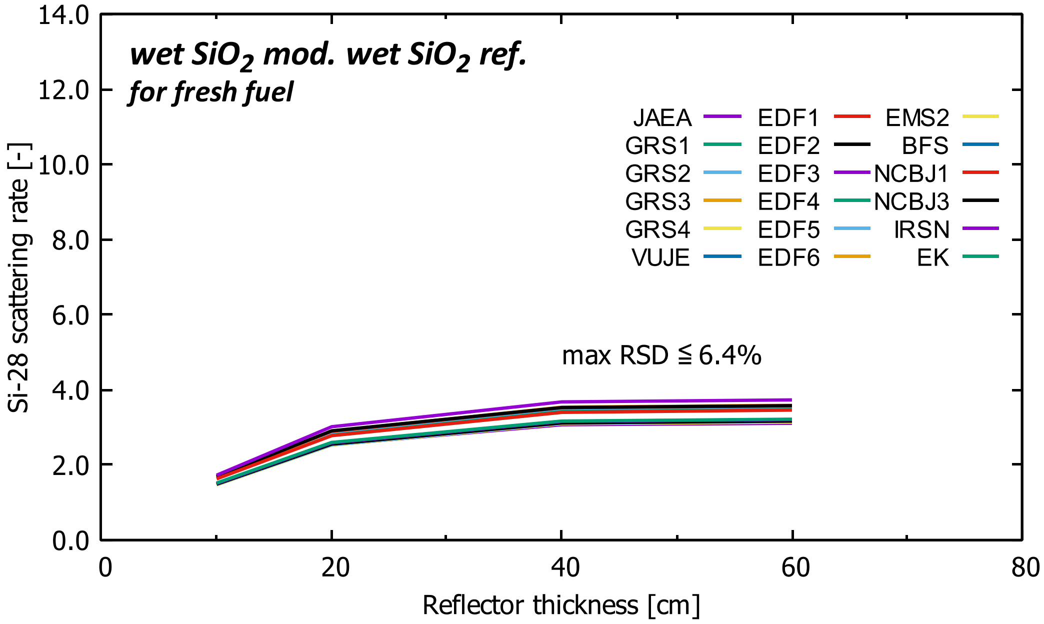


Figure A.72 Reaction rate of ^{28}Si capture against reflector thickness (H_2O moderator and wet SiO_2 reflector for fresh fuel case)

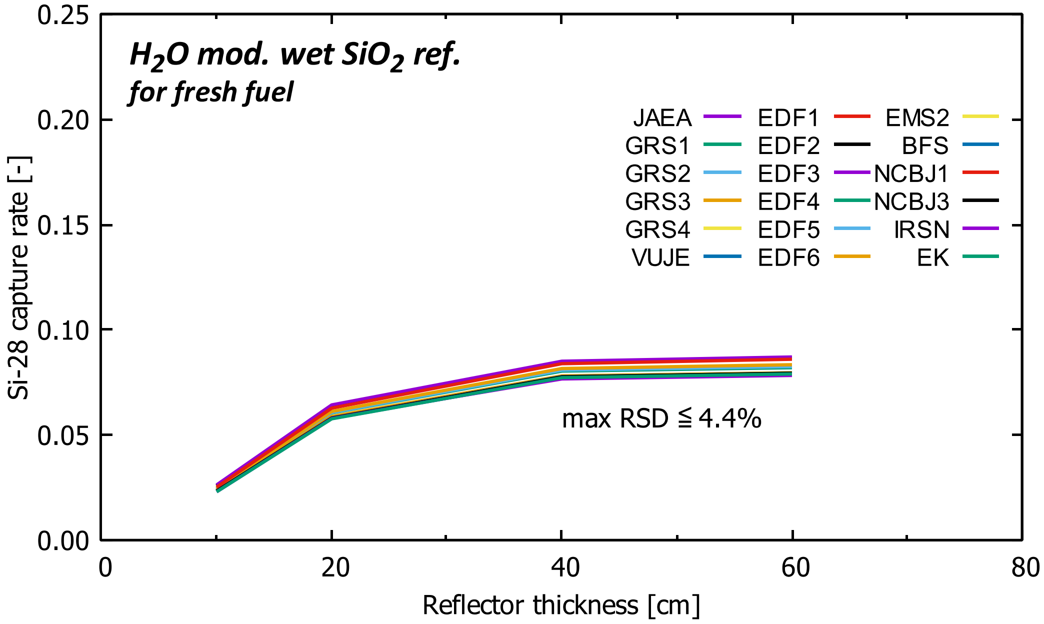


Figure A.73 Reaction rate of ^{28}Si capture against reflector thickness (wet SiO_2 moderator and wet SiO_2 reflector for fresh fuel case)

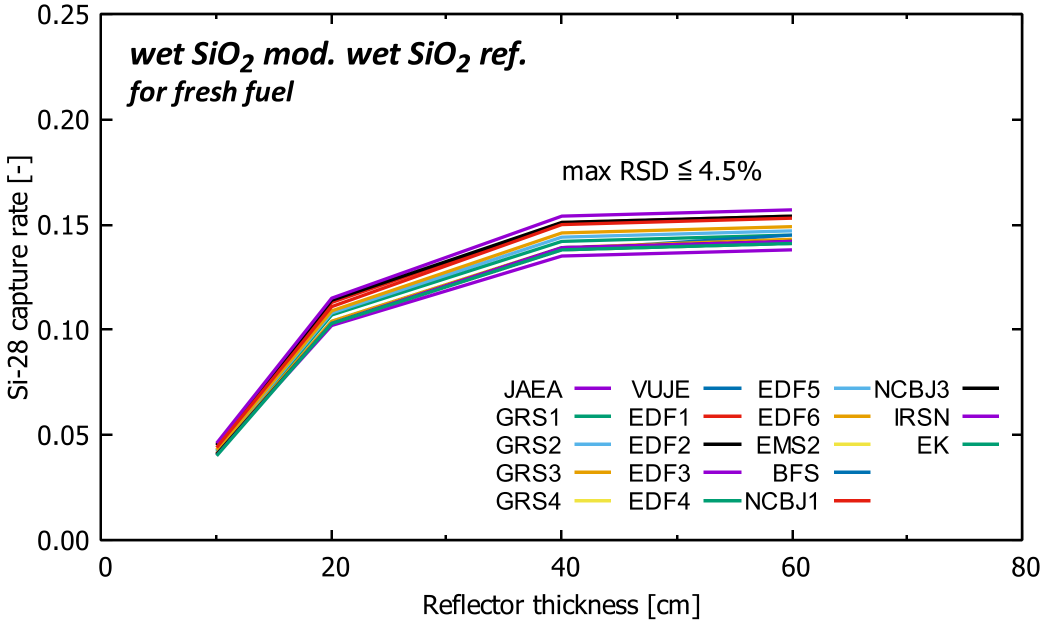


Figure A.74 Reaction rate of ^{1}H scattering against reflector thickness (H_2O moderator and wet SiO_2 reflector for fresh fuel case)

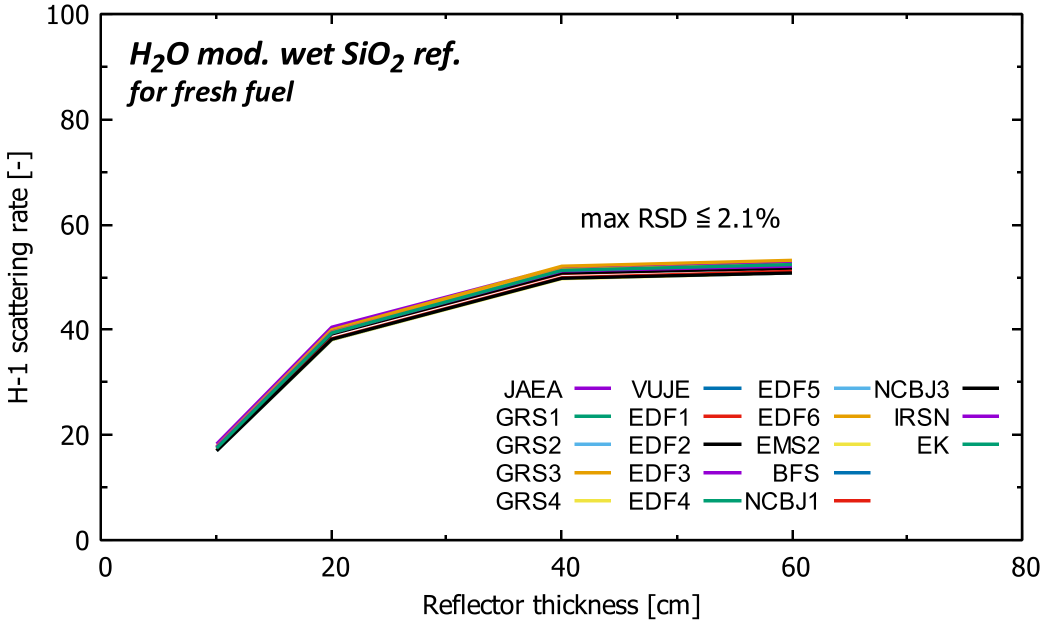


Figure A.75 Reaction rate of [1]H scattering against reflector thickness (H_2O moderator and H_2O reflector for fresh fuel case)

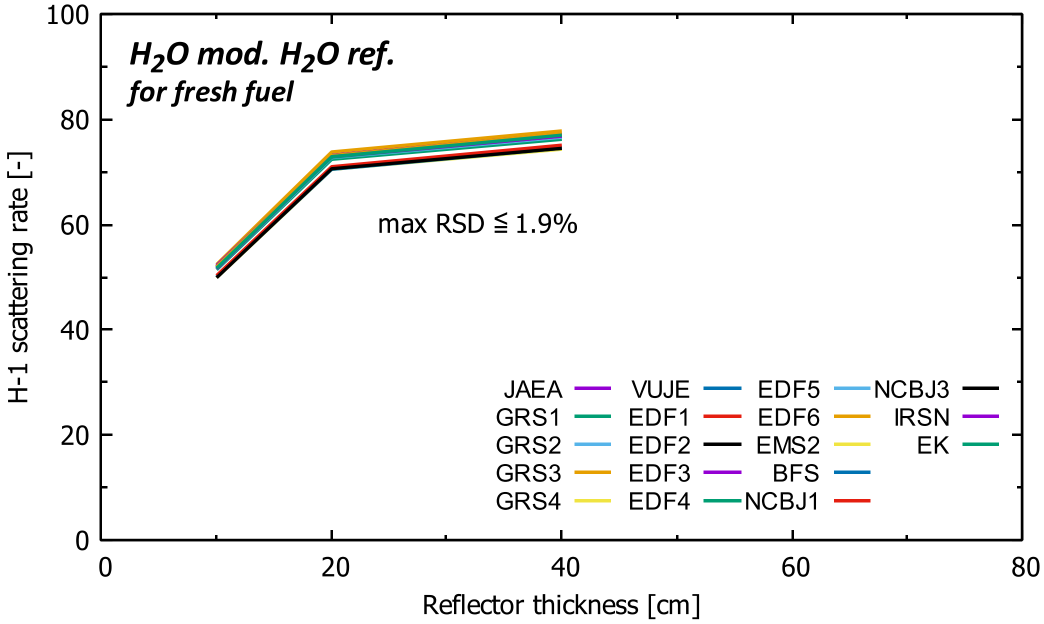


Figure A.76 Reaction rate of [1]H capture against reflector thickness (H_2O moderator and wet SiO_2 reflector for fresh fuel case)

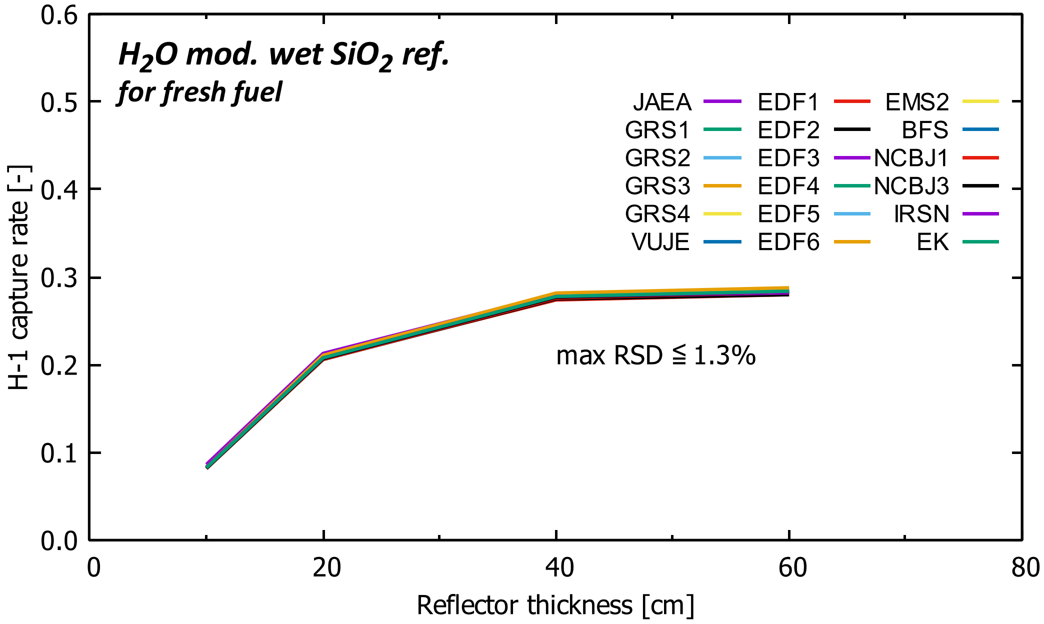


Figure A.77 Reaction rate of [1]H capture against reflector thickness (H_2O moderator and H_2O reflector for fresh fuel case)

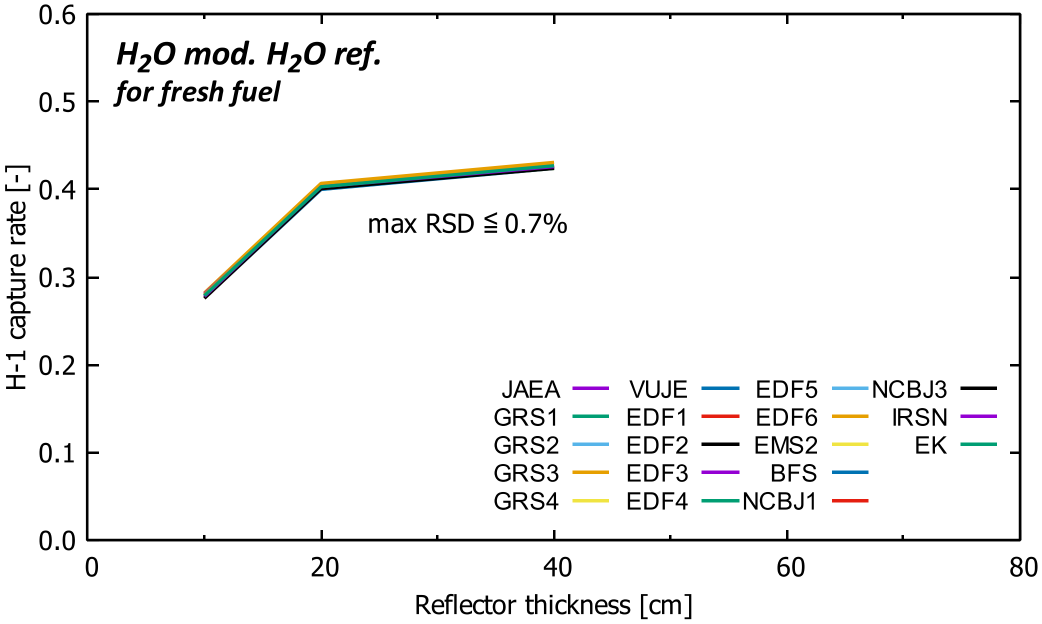


Figure A.78 Reaction rate of [1]H capture against reflector thickness (wet SiO_2 moderator and wet SiO_2 reflector for fresh fuel case)

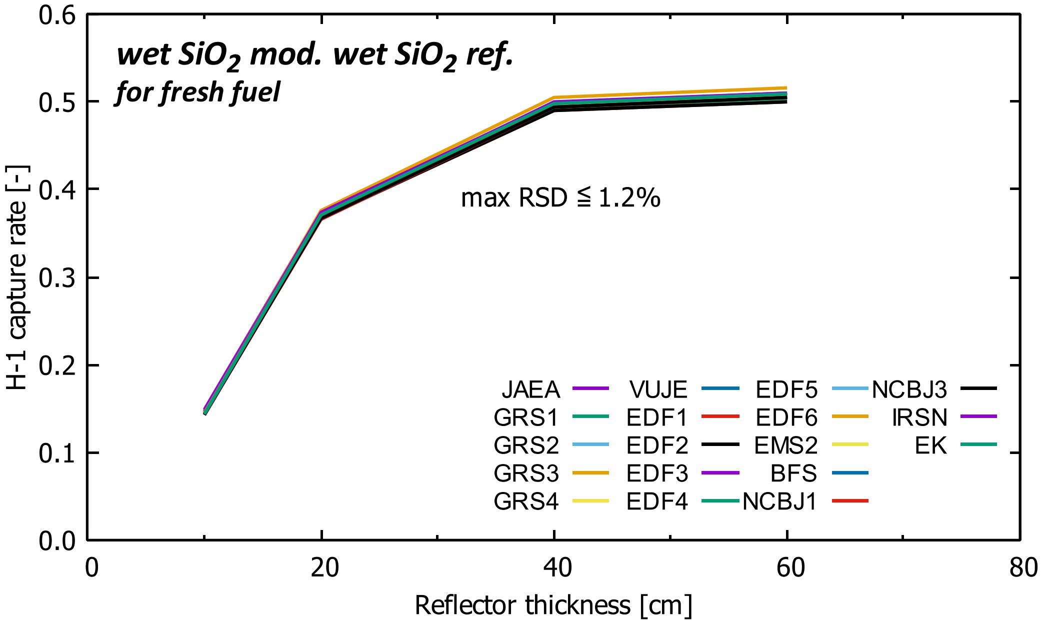


Figure A.79 Absorption/production against reflector thickness (H_2O moderator and dry SiO_2 reflector for fresh fuel case)

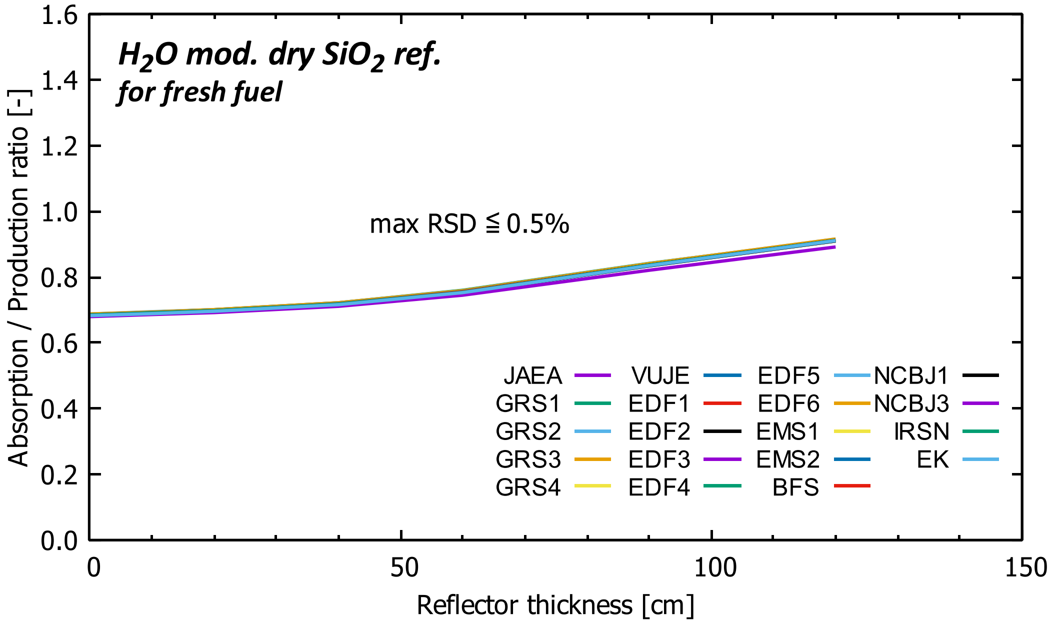


Figure A.80 Absorption/production against reflector thickness (H_2O moderator and wet SiO_2 reflector for fresh fuel case)

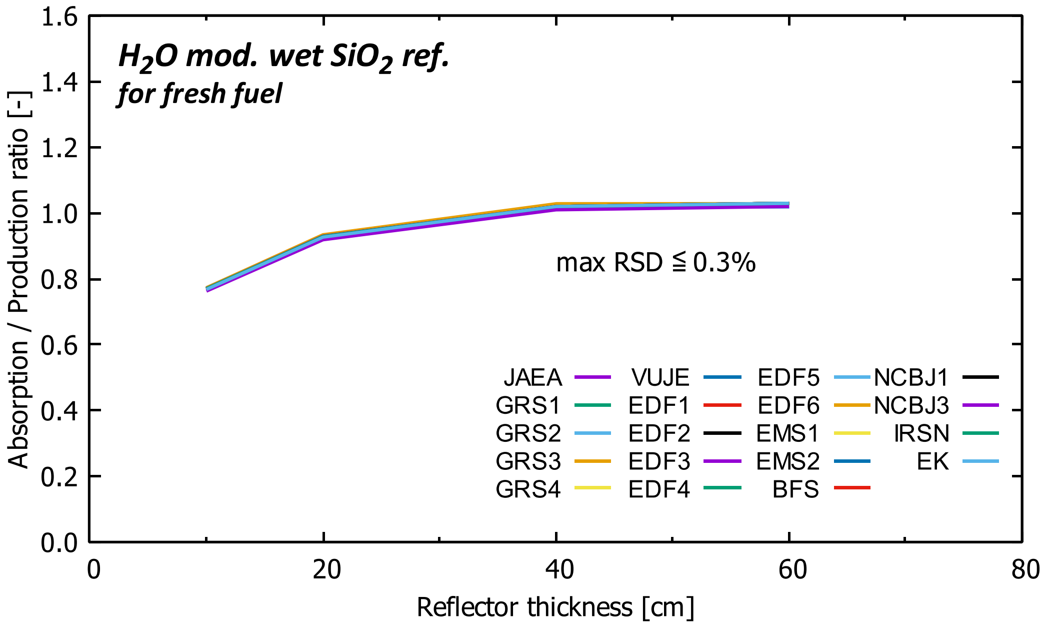


Figure A.81 Absorption/production against reflector thickness
(H_2O moderator and H_2O reflector for fresh fuel case)

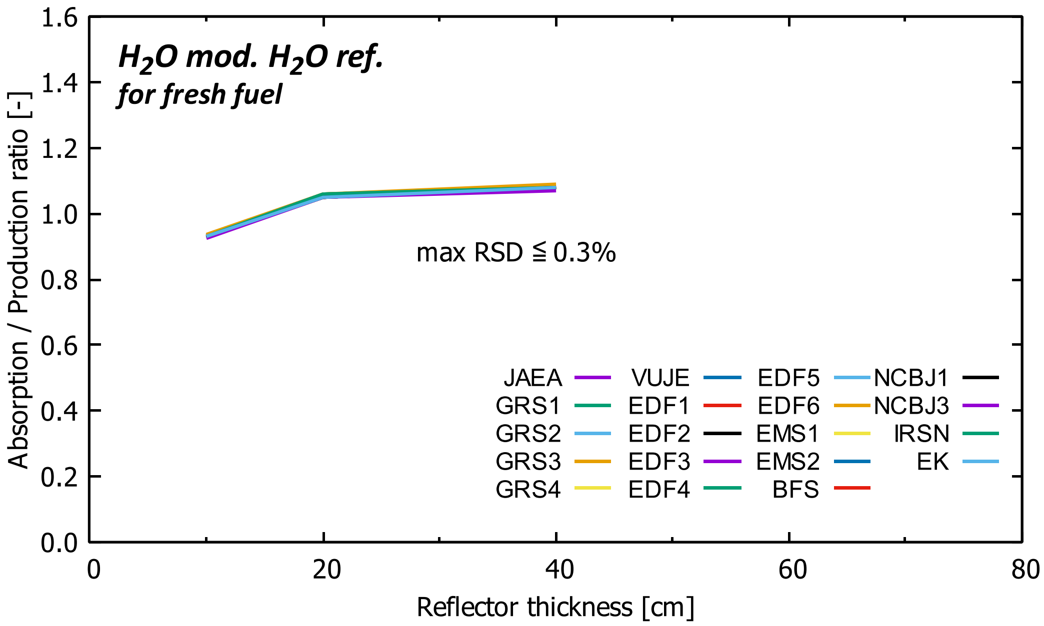


Figure A.82 Absorption/production against reflector thickness
(wet SiO_2 moderator and wet SiO_2 reflector for fresh fuel case)

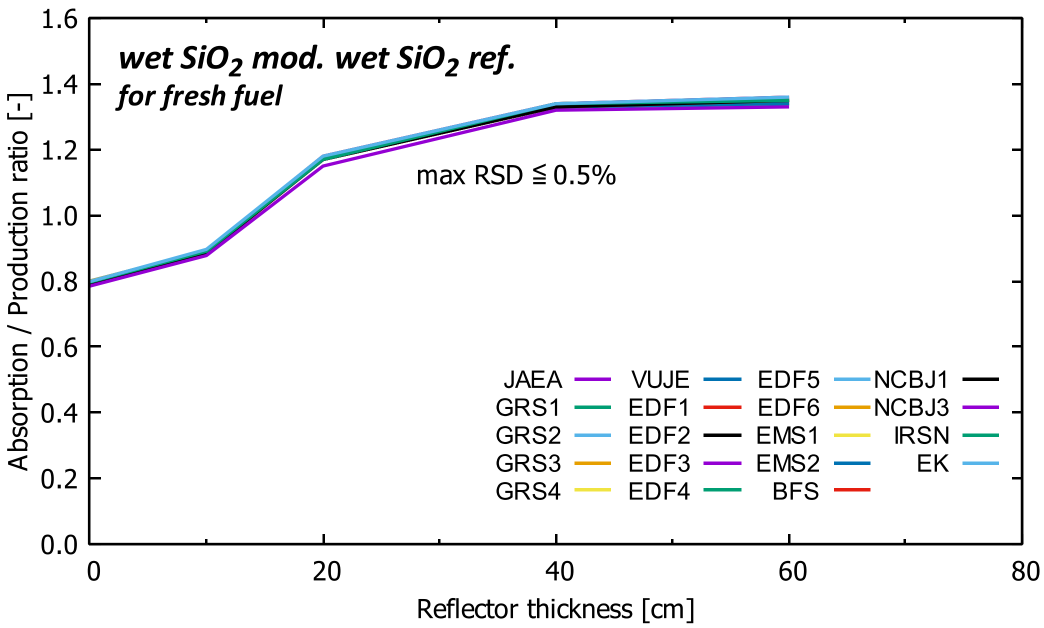


Figure A.83 Leakage/production against reflector thickness (H_2O moderator and dry SiO_2 reflector for fresh fuel case)

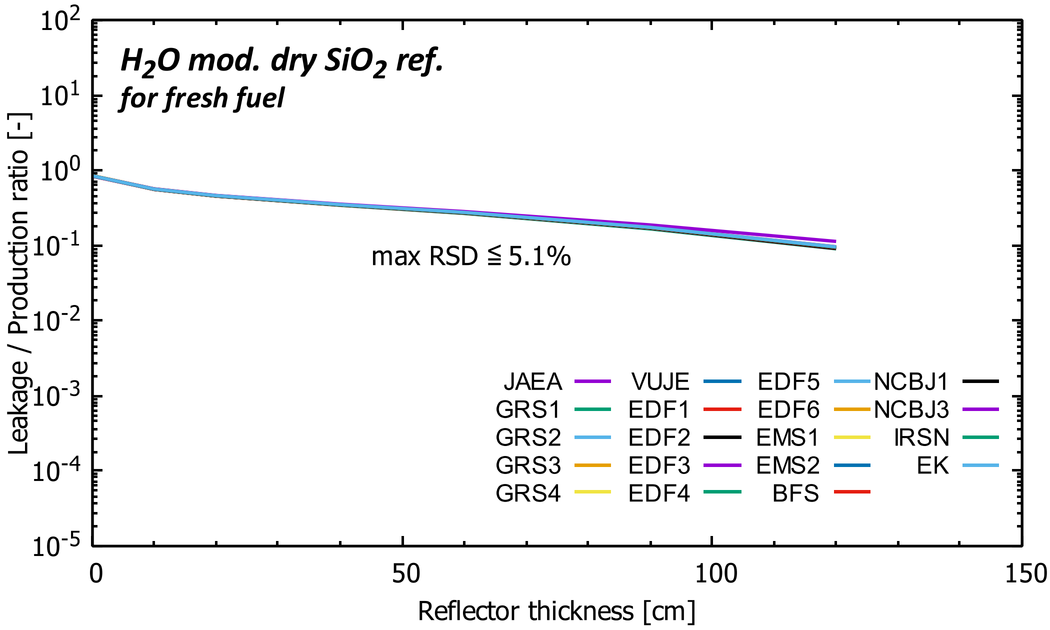


Figure A.84 Leakage/production against reflector thickness (H_2O moderator and wet SiO_2 reflector for fresh fuel case)

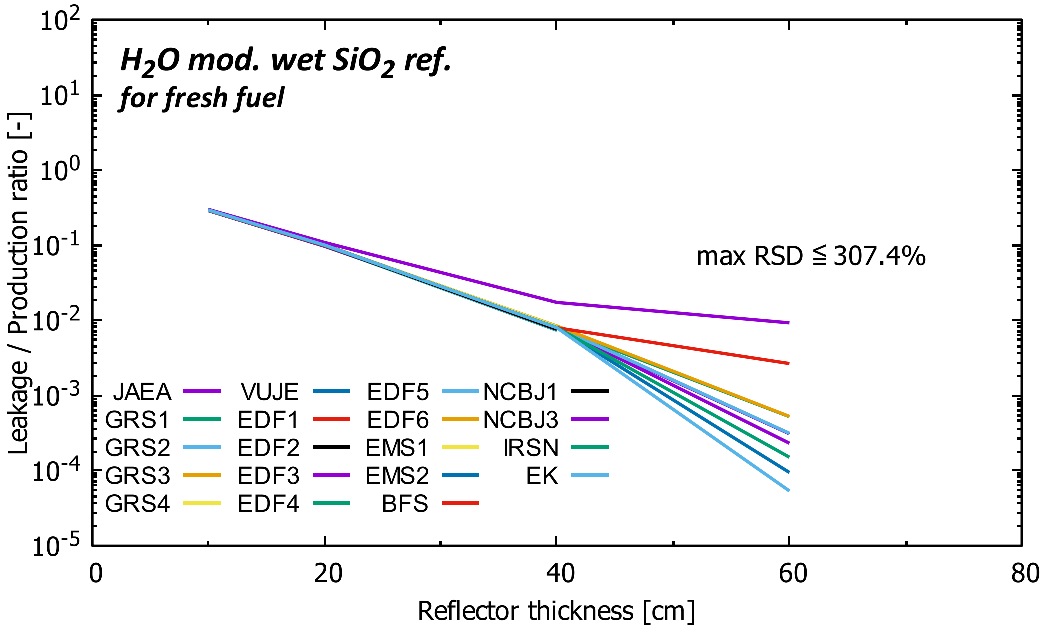


Figure A.85 Leakage/production against reflector thickness
(H_2O moderator and H_2O reflector for fresh fuel case)

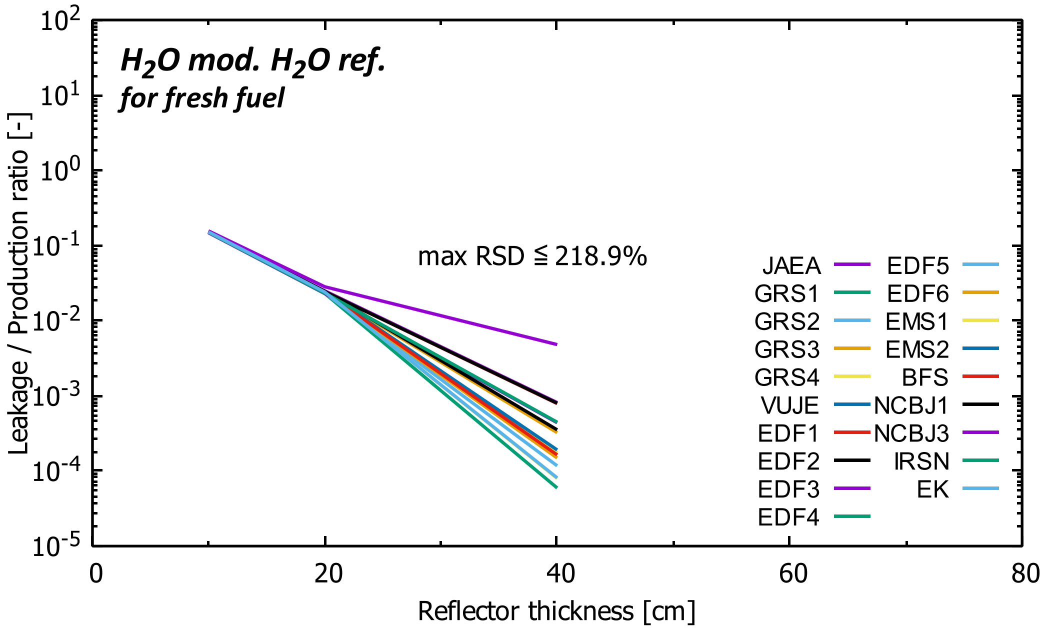


Figure A.86 Leakage/production against reflector thickness
(wet SiO_2 moderator and wet SiO_2 reflector for fresh fuel case)

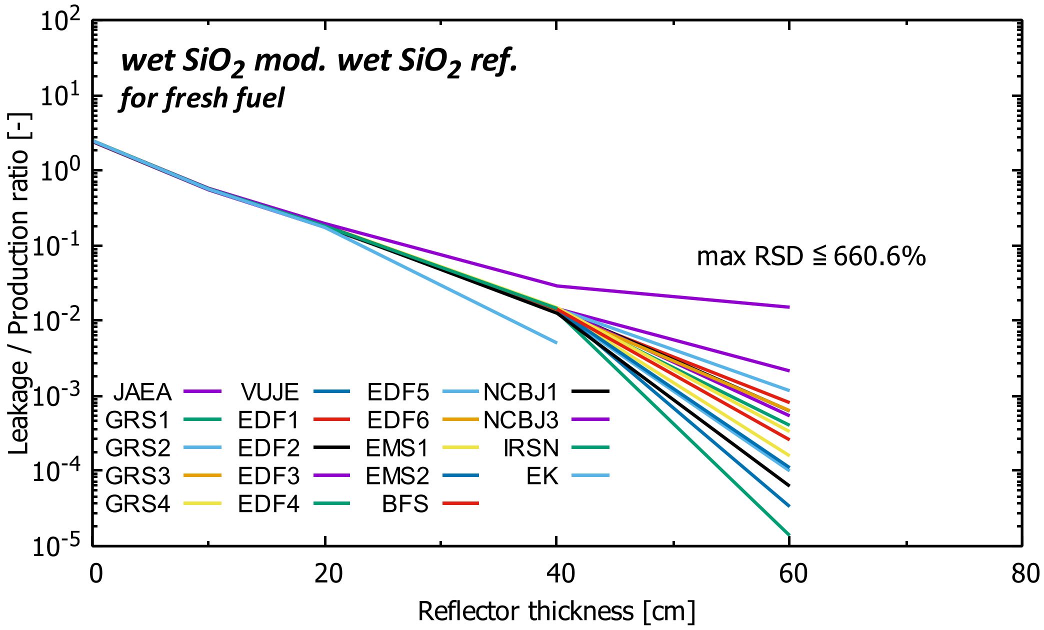


Figure A.87 SI_{th} against reflector thickness (H_2O moderator and dry SiO_2 reflector for fresh fuel case)

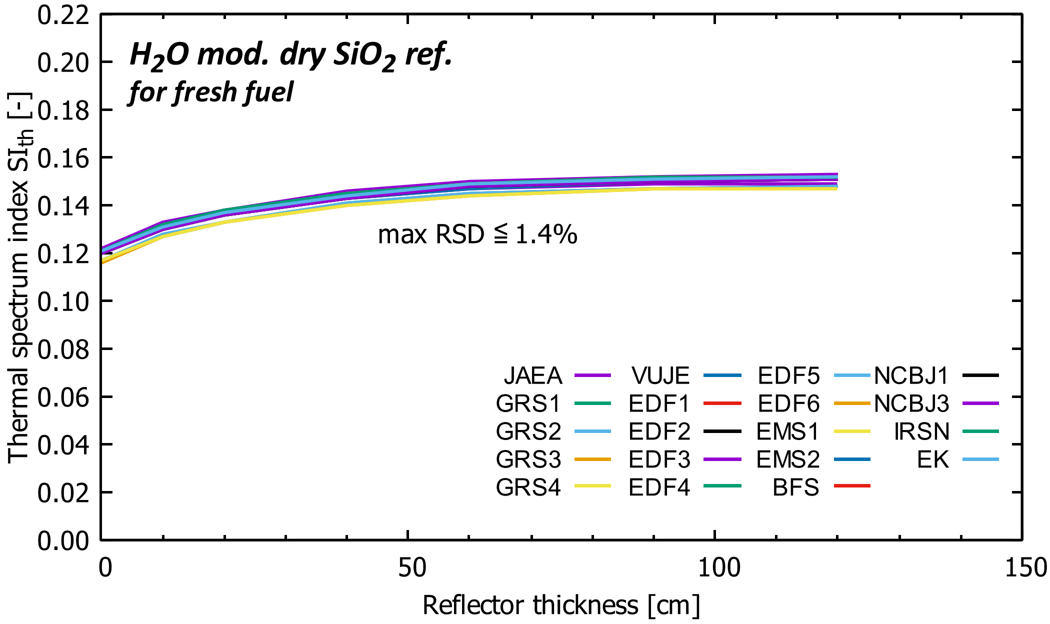


Figure A.88 SI_{th} against reflector thickness (H_2O moderator and wet SiO_2 reflector for fresh fuel case)

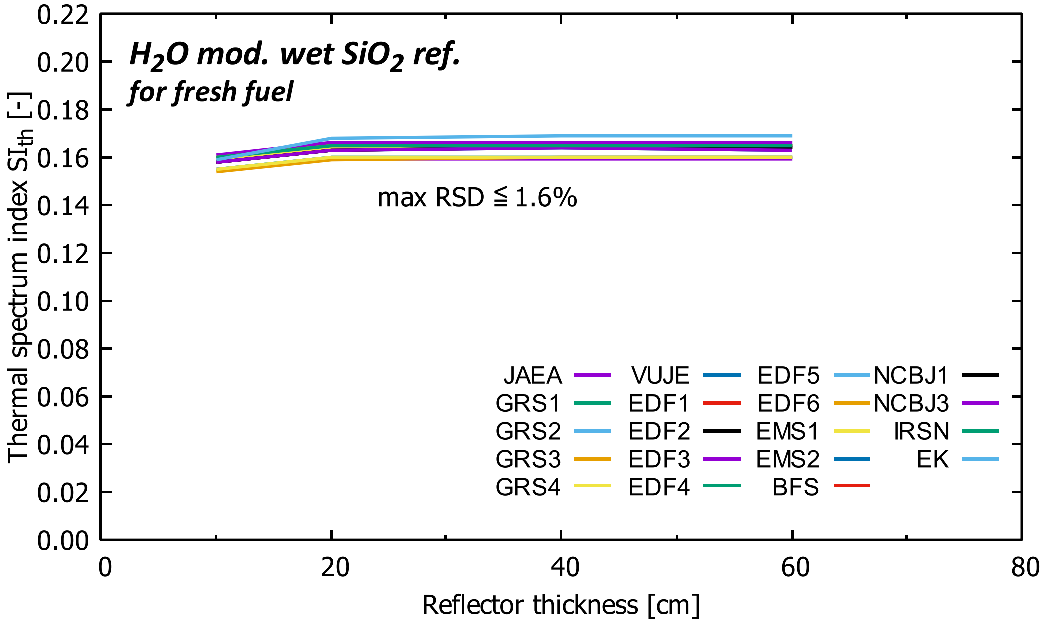


Figure A.89 SI_{th} against reflector thickness (H_2O moderator and H_2O reflector for fresh fuel case)

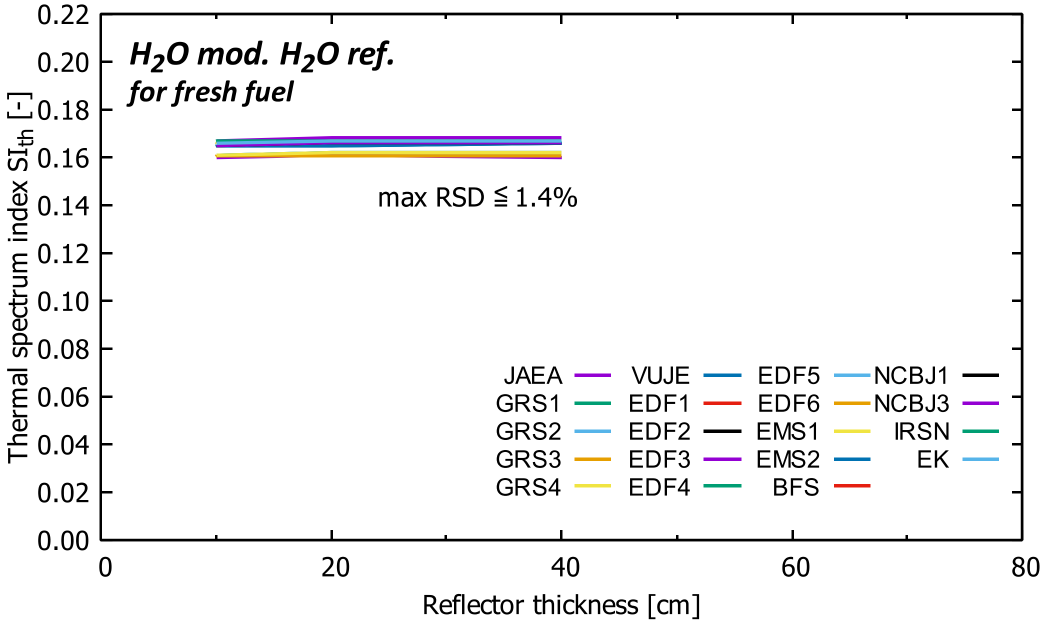
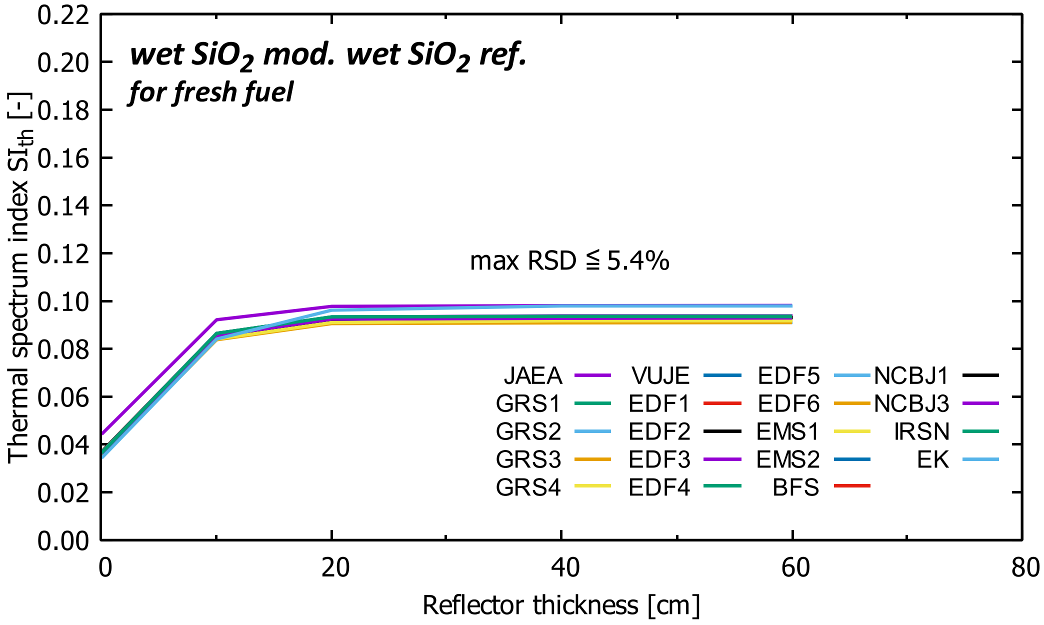


Figure A.90 SI_{th} against reflector thickness (wet SiO_2 moderator and wet SiO_2 reflector for fresh fuel case)



Appendix B. Description of the calculation method used by the participants

1. JAEA

Institute and country: Japan Atomic Energy Agency, Japan.

Participants: Kento Yamamoto, Kenya Suyama, Masaharu Kataoka.

Neutron data library: JENDL-4.0.

Neutron data processing code or method: MVP-II.

Number of neutron energy group: continuous energy.

Description of your code system: MVP-II is a Monte Carlo neutron and photon transport calculation code based on the continuous energy model.

Geometry modelling: No.

Omitted nuclides: No.

Employed convergence limit for eigenvalue calculations: (no information provided by the participants).

Other related information or comment: This calculation was carried out under a contract with METI (Ministry of Economy, Trade and Industry) of Japanese Government in the fiscal years of 2014, 2015 and 2016 as part of its R&D supporting programme for developing geological disposal technology.

References: Nagaya, Y. et al. (2005), *MVP/GMVP II: General Purpose Monte Carlo Codes for Neutron and Photon Transport Calculations based on Continuous Energy and Multi-group Methods*, JAERI 1348.

2. GRS1

Institute and country: Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) gGmbH, Germany.

Participants: Elisabeth Peters, Robert Kilger.

Neutron data library: ENDF/B-V.

Neutron data processing code or method: SCALE 6.1.2 (CSAS5 with CENTRM/PMC).

Number of neutron energy group: 44 groups.

Description of your code system: CSAS5 is a control module of the SCALE 6.1.2 code package, which uses the KENO-V. (a Monte Carlo neutron transport calculation code). KMART5 is used to print out activities for scattering and capture.

Geometry modelling: A three-dimensional geometry is required. First, a fuel cell and a guide tube cell are defined and used in an array function to build up the fuel assembly.

Then, the reflector is modelled as a cuboid enclosing the fuel assembly. A height of 10 cm is adopted for all units with a periodic boundary condition in an axial direction for an infinite dimension.

Omitted nuclides: No.

Employed convergence limit for eigenvalue calculations: 5.00E-5.

Other related information or comment: In the case of silicon, the reaction rates are given for a natural composition, not for ^{28}Si.

Reference: ORNL (2011), *SCALE: A Comprehensive Modeling and Simulation Suite for Nuclear Safety Analysis and Design*, ORNL/TM-2005/39, Version 6.1, available from Radiation Safety Information Computational Centre at Oak Ridge National Laboratory as CCC-785.

3. GRS2

Institute and country: Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) gGmbH, Germany.

Participants: Elisabeth Peters, Robert Kilger.

Neutron data library: ENDF/B-V.

Neutron data processing code or method: SCALE 6.1.2 (CSAS5 with CENTRM/PMC).

Number of neutron energy group: 238 groups.

Description of your code system: CSAS5 is a control module of the SCALE 6.1.2 code package, which uses the KENO-V. (a Monte Carlo neutron transport calculation code). KMART5 is used to print out activities for scattering and capture.

Geometry modelling: A three-dimensional geometry is required. First, a fuel cell and a guide tube cell are defined and used in an array function to build up the fuel assembly. Then, the reflector is modelled as a cuboid enclosing the fuel assembly. A height of 10 cm is adopted for all units with a periodic boundary condition in an axial direction for an infinite dimension.

Omitted nuclides: No.

Employed convergence limit for eigenvalue calculations: 5.00E-5.

Other related information or comment: In the case of silicon, the reaction rates are given for a natural composition, not for ^{28}Si.

Reference: ORNL (2011), *SCALE: A Comprehensive Modelling and Simulation Suite for Nuclear Safety Analysis and Design*, ORNL/TM-2005/39, Version 6.1, available from Radiation Safety Information Computational Centre at Oak Ridge National Laboratory as CCC-785.

4. GRS3

Institute and country: Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) gGmbH, Germany.

Participants: Elisabeth Peters, Robert Kilger.

Neutron data library: ENDF/B-VI.8.

Neutron data processing code or method: SCALE 6.1.2 (CSAS5 with CENTRM/PMC).

Number of neutron energy group: 238 groups.

Description of your code system: CSAS5 is a control module of the SCALE 6.1.2 code package, which uses the KENO-V, (a Monte Carlo neutron transport calculation code). KMART5 is used to print out activities for scattering and capture.

Geometry modelling: A three-dimensional geometry is required. First, a fuel cell and a guide tube cell are defined and used in an array function to build up the fuel assembly. Then, the reflector is modelled as a cuboid enclosing the fuel assembly. A height of 10 cm is adopted for all units with a periodic boundary condition in an axial direction for an infinite dimension.

Omitted nuclides: No.

Employed convergence limit for eigenvalue calculations: 5.00E-5.

Other related information or comment: In the case of silicon, the reaction rates are given for a natural composition, not for ^{28}Si.

Reference: ORNL (2011), *SCALE: A Comprehensive Modelling and Simulation Suite for Nuclear Safety Analysis and Design*, ORNL/TM-2005/39, Version 6.1, available from Radiation Safety Information Computational Centre at Oak Ridge National Laboratory as CCC-785.

5. GRS4

Institute and country: Gesellschaft für Anlagen- und Reaktorsicherheit (GRS) gGmbH, Germany.

Participants: Elisabeth Peters, Robert Kilger.

Neutron data library: ENDF/B-VII.0.

Neutron data processing code or method: SCALE 6.1.2 (CSAS5 with CENTRM/PMC).

Number of neutron energy group: 238 groups.

Description of your code system: CSAS5 is a control module of the SCALE 6.1.2 code package, which uses the KENO-V, (a Monte Carlo neutron transport calculation code). KMART5 is used to print out activities for scattering and capture.

Geometry modelling: A three-dimensional geometry is required. First, a fuel cell and a guide tube cell are defined and used in an array function to build up the fuel assembly. Then, the reflector is modelled as a cuboid enclosing the fuel assembly. A height of 10 cm is adopted for all units with a periodic boundary condition in an axial direction for an infinite dimension.

Omitted nuclides: No.

Employed convergence limit for eigenvalue calculations: 5.00E-5.

Reference: ORNL (2011), *SCALE: A Comprehensive Modelling and Simulation Suite for Nuclear Safety Analysis and Design*, ORNL/TM-2005/39, Version 6.1, available from Radiation Safety Information Computational Centre at Oak Ridge National Laboratory as CCC-785.

6. VUJE

Institute and country: VUJE, Slovak Republic.

Participant: Vladimir Chrapciak.

Neutron data library: ENDF/B-VII.0.

Neutron data processing code or method: SCALE 6.1.2.

Number of neutron energy group: 238 groups.

Description of your code system: The SCALE 6.1.2 system, a KENO-VI module. Library v7-238 and continuous energy model.

Geometry modelling: No.

Omitted nuclides: No.

Employed convergence limit for eigenvalue calculations: (no information provided by the participants).

Other related information or comment: GEN=950, NPG=5000, NSKIP=150.

Reference: ORNL (2011), *SCALE: A Comprehensive Modeling and Simulation Suite for Nuclear Safety Analysis and Design*, ORNL/TM-2005/39, Version 6.1, available from Radiation Safety Information Computational Center at Oak Ridge National Laboratory as CCC-785.

7. EDF1

Institute and country: EDF Energy Generation, UK.

Participant: Derek Putley.

Neutron data library: JEF 2.2.

Neutron data processing code or method: MONK9A (DICE).

Number of neutron energy group: “continuous energy” or hyperfine multi-group (13 193 groups).

Description of your code system: MONK − A Monte Carlo programme for nuclear criticality safety and reactor physics analyses.

Geometry modelling: A three-dimensional model based on the benchmark specification. An arbitrary fuel length of 3.6 m was modelled with a full periodic reflection at each end of the fuel.

Omitted nuclides: In the moderator and reflector all O was modelled as ^{16}O and all H was modelled as ^{1}H bound in the water. All Si was modelled as natural Si and the scattering and capture results are data for natural Si as opposed to the ^{28}Si nuclide.

Employed convergence limit for eigenvalue calculations: A target Monte Carlo standard error of 0.0003 on k-effective was used for all calculations.

Other related information or comment: All of these tests used MONK9A, an update 1, running on Red Hat linux. The MONK nuclear data file used was dice96j2v10.dat.

Reference: MONK − A Monte Carlo programme for nuclear criticality safety and reactor physics analyses, http://www.answerssoftwareservice.com/monk/.

8. EDF2

Institute and country: EDF Energy Generation, UK.

Participant: Derek Putley.

Neutron data library: JEF 2.2.

Neutron data processing code or method: MONK9A (DICE).

Number of neutron energy group: “continuous energy” or hyperfine multi-group (13 193 groups).

Description of your code system: MONK − A Monte Carlo programme for nuclear criticality safety and reactor physics analyses.

Geometry modelling: A three-dimensional model based on the benchmark specification. An arbitrary fuel length of 3.6 m was modelled with a full periodic reflection at each end of the fuel.

Omitted nuclides: In the moderator and reflector all O was modelled as natural O and all H was modelled as natural H bound in the water. MONK9A breaks these down into various nuclides. As requested, the scattering and capture results are for ^{16}O and ^{1}H only. All Si was modelled as natural Si and the scattering and capture results are data for natural Si and not ^{28}Si.

Employed convergence limit for eigenvalue calculations: A target Monte Carlo standard error of 0.0003 on k-effective was used for all calculations.

Other related information or comment: This case was conducted as a variant of other MONK9A/DICE/JEF2.2 case, to test the sensitivity of the results regarding the coding of O and H as natural elements instead of using ^{16}O and ^{1}H. All of these tests used MONK9A, an update 1, running on Red Hat linux. The MONK nuclear data file used was dice96j2v10.dat.

Reference: MONK − A Monte Carlo programme for nuclear criticality safety and reactor physics analyses, http://www.answerssoftwareservice.com/monk/.

9. EDF3

Institute and country: EDF Energy Generation, UK.

Participant: Derek Putley.

Neutron data library: JENDL 3.2.

Neutron data processing code or method: MONK9A (DICE).

Number of neutron energy group: “continuous energy” or hyperfine multi-group (13 193 groups).

Description of your code system: MONK − A Monte Carlo program for nuclear criticality safety and reactor physics analyses.

Geometry modelling: A three-dimensional model based on the benchmark specification. An arbitrary fuel length of 3.6 m was modelled with a full periodic reflection at each end of the fuel.

Omitted nuclides: In the moderator and reflector all O was modelled as ^{16}O and all H was modelled as ^{1}H bound in the water. All Si was modelled as natural Si and the scattering and capture results are data for natural Si and not ^{28}Si.

Employed convergence limit for eigenvalue calculations: A target Monte Carlo standard error of 0.0003 on k-effective was used for all calculations.

Other related information or comment: All of these tests used MONK9A, an update 1, running on Red Hat linux. The MONK nuclear data file used was dice00jn3v3.dat.

Reference: MONK − A Monte Carlo programme for nuclear criticality safety and reactor physics analyses, http://www.answerssoftwareservice.com/monk/.

10. EDF4

Institute and country: EDF Energy Generation, UK.

Participant: Derek Putley.

Neutron data library: JEFF 3.1.2.

Neutron data processing code or method: MONK10A (BINGO).

Number of neutron energy group: Continuous energy.

Description of your code system: MONK − A Monte Carlo programme for nuclear criticality safety and reactor physics analyses.

Geometry modelling: A three-dimensional model based on the benchmark specification. An arbitrary fuel length of 3.6 m was modelled with a full periodic reflection at each end of the fuel.

Omitted nuclides: In the moderator and reflector all O was modelled as ^{16}O and all H was modelled as ^{1}H bound in the water. All Si was input as natural Si but MONK10A changed this into discrete Si nuclides so the scattering and capture results are for ^{28}Si.

Employed convergence limit for eigenvalue calculations: A target Monte Carlo standard error of 0.0003 on k-effective was used for all calculations.

Other related information or comment: All of these tests used MONK10A, an update 0, running on Red Hat linux. The MONK nuclear data library used was bingordb_j312v1.

Reference: MONK − A Monte Carlo programme for nuclear criticality safety and reactor physics analyses, http://www.answerssoftwareservice.com/monk/.

11. EDF5

Institute and country: EDF Energy Generation, UK.

Participant: Derek Putley.

Neutron data library: ENDF-B/VII.0.

Neutron data processing code or method: MONK10A (BINGO).

Number of neutron energy group: Continuous energy.

Description of your code system: MONK − A Monte Carlo programme for nuclear criticality safety and reactor physics analyses.

Geometry modelling: A three-dimensional model based on the benchmark specification. An arbitrary fuel length of 3.6 m was modelled with a full periodic reflection at each end of the fuel.

Omitted nuclides: In the moderator and reflector all O was modelled as ^{16}O and all H was modelled as ^{1}H bound in the water. All Si was input as natural Si but MONK10A changed this into discrete Si nuclides so the scattering and capture results are for ^{28}Si.

Employed convergence limit for eigenvalue calculations: A target Monte Carlo standard error of 0.0003 on k-effective was used for all calculations.

Other related information or comment: All of these tests used MONK10A, an update 0, running on Red Hat linux. The MONK nuclear data library used was bingordb_e70v2.

Reference: MONK − A Monte Carlo program for nuclear criticality safety and reactor physics analyses, http://www.answerssoftwareservice.com/monk/.

12. EDF6

Institute and country: EDF Energy Generation, UK.

Participant: Derek Putley.

Neutron data library: CENDL-3.1.

Neutron data processing code or method: MONK10A (BINGO).

Number of neutron energy group: Continuous energy.

Description of your code system: MONK − A Monte Carlo programme for nuclear criticality safety and reactor physics analyses.

Geometry modelling: A three-dimensional model based on the benchmark specification. An arbitrary fuel length of 3.6 m was modelled with a full periodic reflection at each end of the fuel.

Omitted nuclides: In the moderator and reflector all O was modelled as ^{16}O and all H was modelled as ^{1}H bound in the water. All Si was input as natural Si but MONK10A changed this into discrete Si nuclides so the scattering and capture results are for ^{28}Si.

Employed convergence limit for eigenvalue calculations: A target Monte Carlo standard error of 0.0003 on k-effective was used for all calculations.

Other related information or comment: All of these tests used MONK10A, an update 0, running on Red Hat linux. The MONK nuclear data library used was bingordb_c31v1.

Reference: MONK − A Monte Carlo programme for nuclear criticality safety and reactor physics analyses, http://www.answerssoftwareservice.com/monk/.

13. EMS1

Institute and country: E Mennerdahl Systems (EMS), Sweden.

Participant: Dennis Mennerdahl.

Neutron data library: ENDF/B-VII.0.

Neutron data processing code or method: SCALE-6.2b4 (AMPX-2000).

Number of neutron energy group: 238 groups.

Description of your code system: SCALE 6.2 beta 4, under development, with the KENO-V. a Monte Carlo calculation code system.

Geometry modelling: Infinite axial dimensions by 20 cm height and mirror reflection.

Omitted nuclides: No.

Employed convergence limit for eigenvalue calculations: No predetermined convergence limit.

Other related information or comment: Inelastic scattering (MT=4) of ^{1}H not included in the cross-section library and calculated as 0. The publication of the results based on SCALE 6.2 beta 4 version, which is subject to approval by the code developers of ORNL.

Reference: ORNL (2011), *SCALE: A Comprehensive Modelling and Simulation Suite for Nuclear Safety Analysis and Design*, ORNL/TM-2005/39, Version 6.1.

14. EMS2

Institute and country: E Mennerdahl Systems (EMS), Sweden.

Participant: Dennis Mennerdahl.

Neutron data library: ENDF/B-VII.1.

Neutron data processing code or method: SCALE-6.2b4 (AMPX-2000).

Number of neutron energy group: Continuous energy.

Description of your code system: SCALE 6.2 beta 4, under development, with the KENO-V. a Monte Carlo calculation code system.

Geometry modelling: Infinite axial dimensions by 20 cm height and mirror reflection.

Omitted nuclides: No.

Employed convergence limit for eigenvalue calculations: No predetermined convergence limit.

Other related information or comment: Features for calculating CE reaction data is planned for SCALE 6.2. Preliminary results have been obtained but will not be reported for the beta 4 version due to some complications. The publication of the results based on SCALE 6.2 beta 4 version is subject to approval by the code developers of ORNL.

Reference: ORNL (2011), *SCALE: A Comprehensive Modeling and Simulation Suite for Nuclear Safety Analysis and Design*, ORNL/TM-2005/39, Version 6.1.

15. BFS

Institute and country: Bundesamt für Strahlenschutz (BfS), Germany.

Participants: Benjamin Ruprecht, Ingo Reiche.

Neutron data library: SCALE library based on ENDF/B-VII.0.

Neutron data processing code or method: CENTRM/BONAMI/PMC (SCALE 6.1.3).

Number of neutron energy group: 238 groups.

Description of your code system: SCALE 6.1.3 code system using CSAS5, which is a control module for k_{eff} calculations with KENO-V. KENO-V. is a functional module in the SCALE system and in the three-dimensional Monte Carlo criticality programme.

Geometry modelling: Three-dimensional SCALE generalised geometry package model in KENO-V.a.

Omitted nuclides: No.

Employed convergence limit for eigenvalue calculations: 20 pcm statistical uncertainty.

References: Bowman, S.M. (2011), "SCALE 6: Comprehensive nuclear safety analysis code system", *Nucl. Technol.*, Vol. 174(2), pp. 126-148.

Williams, M.L. and G. Ilas (2009), "ENDF/B-VII nuclear data libraries for SCALE 6", *Advances in Nuclear Fuel Management IV (ANFM 2009),* Hilton Head Island, South Carolina, US, 12-15 April 2009, CD-ROM, *American Nuclear Society*, LaGrange Park, IL.

16. NCBJ1

Institute and country: National Centre for Nuclear Research, Poland.

Participant: Agnieszka Boettcher.

Neutron data library: ENDF/B-VII.0.

Neutron data processing code or method: MCNPX-2.7.0.

Number of neutron energy group: Continuous energy.

Description of your code system: Monte Carlo N-Paricle code.

Geometry modelling: (no information provided by the participants).

Omitted nuclides: No.

Employed convergence limit for eigenvalue calculations: (no information provided by the participants).

Reference: *MCNP − A General Monte Carlo N-Particle Transport Code*, User's guide X-5 Monte Carlo Team, Los Alamos National Laboratory.

17. NCBJ3

Institute and country: National Centre for Nuclear Research, Poland.

Participants: Łukasz Koszuk, Małgorzata Klisińska.

Neutron data library: ENDF/B-VII.0.

Neutron data processing code or method: KENO-VI - SCALE 6.1.3.

Number of neutron energy group: 238 groups.

Description of your code system: KENO-VI is an extension of the KENO Monte Carlo criticality programme developed for the SCALE system.

Geometry modelling: Yes.

Omitted nuclides: No.

Employed convergence limit for eigenvalue calculations: (no information provided by the participants).

Reference: Hollenbach, D.F.et al. (2011), *KENO-VI: A General Quadratic Version of the KENO Program*, Oak Ridge National Laboratory, ORNL/TM-2005/39.

18. IRSN

Institute and country: IRSN, France.

Participant: Ludyvine Jutier.

Neutron data library: JEFF-3.1.0.

Neutron data processing code or method: MORET5B2.

Number of neutron energy group: Continuous energy.

Description of your code system: MORET5B2 is a simulation tool that solves the transport equation for neutrons using the Monte Carlo method.

Geometry modelling: (no information provided by the participants).

Omitted nuclides: No.

Employed convergence limit for eigenvalue calculations: (no information provided by the participants).

Reference: Cochet, B. et al. (2014), "Capabilities overview of the MORET 5 Monte Carlo code", *Annals of Nuclear Energy*, http://dx.doi.org/10.1016/j.anucene.2014.08.022.

19. EK

Institute and country: Centre for Energy Research (EK), Hungary.

Participant: Gabor Hordosy.

Neutron data library: ENDF/B-VII.0.

Neutron data processing code or method: MCNP5-1.60.

Number of neutron energy group: Continuous energy.

Description of your code system: MCNP5 1.60 is a Monte Carlo neutron and photon transport calculation code based on the continuous energy model.

Geometry modelling: (no information provided by the participants).

Omitted nuclides: No.

Employed convergence limit for eigenvalue calculations: Source entropy.

Reference: *MCNP − A General n-particle Transport Code*, version 5, LA-CP-03-0245.

Appendix C. Benchmark specification

C.1 Introduction

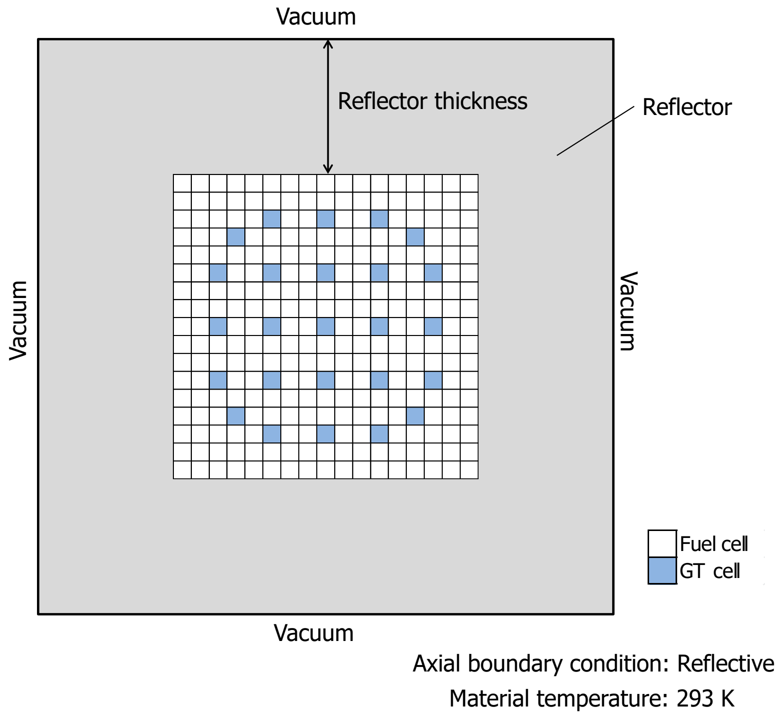
In the criticality safety evaluation for the direct disposal of UNF, the geometrical configuration consisting of fuel assemblies, steel container, clay buffer material and rock ground around the container can be calculation objectives. The steel might corrode over the long-term time frame of the geological disposal and the thickness of the steel container wall might become thinner. Thus, the clay buffer material or the rock ground can be a neutron reflector surrounding the fuel component. The reflector of these materials could give larger reactivity effect than the water reflector, which is the usual model in the criticality evaluation. However, the reflector effect of these materials has not been investigated in detail. To perform the accurate criticality evaluation in the direct disposal of UNF, it is necessary to validate the calculation tools and the nuclear data library. First, it is necessary to ensure that the reflector effect of these materials is consistent for different nuclear data and calculation tools by comparing relevant important parameters, such as the neutron multiplication factor or the reaction rate. In this benchmark, the main focus is placed on silicon dioxide (SiO_2), as SiO_2 is a major component of these materials.

This benchmark consists of two parts: fresh fuel and used fuel. A simple geometry model concerning the reflector effect is assumed for both parts. In the second part, the concept of the burn-up credit is taken into account. The aim of the first part is to compare the SiO_2 reflector effect for simplified condition. The aim of the second part is to compare the SiO_2 reflector effect adopting the realistic fuel composition in the direct disposal.

C.2 Geometry specification

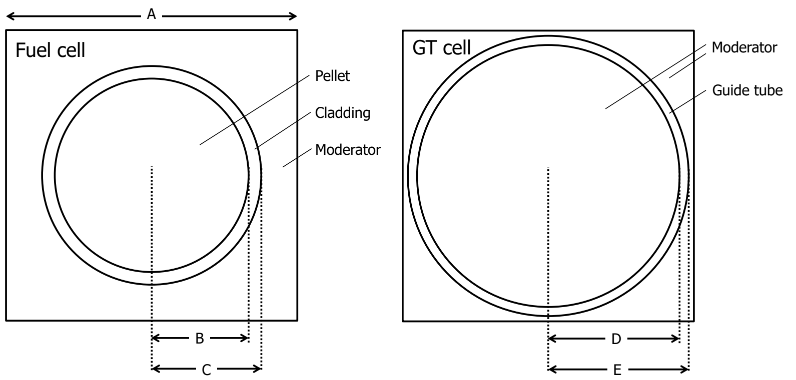
Figure C.1 shows the 17 × 17 type PWR fuel assembly with a reflector in a two-dimensional system. The vacuum boundary condition in the radial direction and the infinite dimension in the axial direction are adopted. A number of sets of reflector materials and thicknesses are applied, which are described in Section C.5. The specification of the fuel rod and the guide tube is shown in Figure C.2. The moderator region shown in Figure C.2 is assumed to be filled with water or clay material containing water. The former is applied considering severe accidents in criticality safety. The latter is applied considering more realistic cases in the configuration of disposal of used fuel. The temperature of 293 Kelvin is assumed for all materials.

Figure C.1 Schematic geometrical model for benchmark problem



Source: JAEA, 2019.

Figure C.2 Geometrical specification of fuel rod and guide tube



Symbol		
A	Fuel rod pitch (cm)	1.265
	Fuel rod	
B	Radius of pellet (cm)	0.412
C	Outer radius of cladding tube (cm)	0.476
	Guide tube	
D	Inner radius of tube (cm)	0.570
E	Outer radius of tube (cm)	0.610

Source: Yamamoto et al., 2002.

C.3 Material specification

Reflector material

Three types of reflector materials are considered in this benchmark. First, SiO_2 of 1.6 g/cc dry density is chosen. No water content is assumed for this material for simplicity. The dry density corresponds to the natural property of the mixture material consisting of 70% bentonite and 30% silica sand, which is a candidate for the clay buffer material in the geological disposal [2]. The chemical composition of this mixture is assumed to be 100% SiO_2 for simplicity. This assumption is ensured to be conservative for criticality safety by some pre-evaluations. Second, SiO_2 containing water with the water-saturated condition, where the air void of clay material is completely filled with water, is chosen for the more realistic material model. Finally, water is chosen as the reference material in order to compare the reflector effect between SiO_2 and water. The specifications of three types of the reflector materials are shown in Table C.1.

Table C.1 Specification of reflector materials

Material	SiO_2 (dry)	SiO_2 (wet)	H_2O
Density (g/cc)			
SiO_2	1.6	1.6	–
H_2O	0	0.4067	0.9983
Number density (#/barn/cm)			
H	–	2.7190E-02	6.6742E-02
O	3.2073E-02	4.5668E-02	3.3371E-02
Si	1.6037E-02	1.6037E-02	–

Source: JAEA, 2019.

Other materials

The compositions of the moderator region and cladding tube are shown in Table C.2. The same material compositions in Table C.1 are applied for the moderator materials. The composition of cladding tube is assumed to be natural zirconium rather than zircalloy for simplicity. The grid spacer is neglected for simplicity.

Table C.2 Specification of moderator and cladding tube

		Moderator		Cladding tube
Material	Element	H_2O	SiO_2 (wet)	Zr-nat
Number density (#/barn/cm)	H	6.6742E-02	2.7190E-02	–
	O	3.3371E-02	4.5668E-02	–
	Si	–	1.6037E-02	–
	Zr	–	–	4.3108E-02

Source: JAEA, 2019.

C.4 Fuel composition

Fresh fuel

In this benchmark, 4.5 wt% ^{235}U enrichment PWR UO_2 fuel is selected. The number density of fresh fuel is shown in Table C.3.

Table C.3 Number density of fresh fuel

Number density (#/barn/cm)	
^{235}U	1.0468E-03
^{238}U	2.1935E-02
^{16}O	4.5963E-02

Source: JAEA, 2019.

Used fuel

Several combinations of assembly burn-up values and decay times are selected. These specifications are described below.

Assembly burn-up value

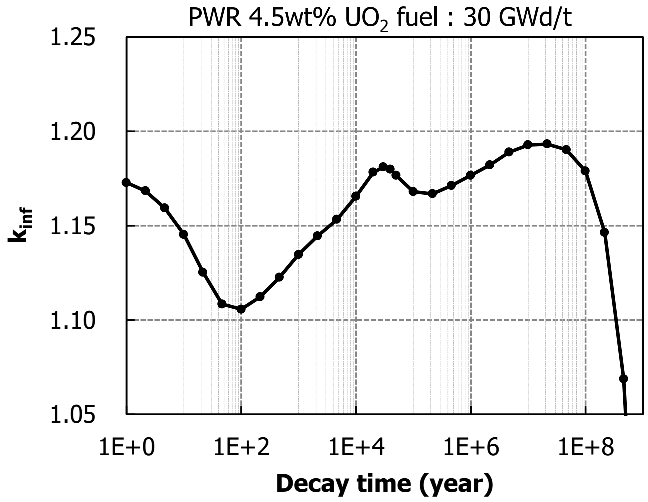
The representative burn-up values, 30 and 45 GWd/t, are selected. 45 GWd/t is selected as the usual spent nuclear fuel and 30 GWd/t is considered as the intermediate case in order to understand the influence of the burn-up value on the reflector effect.

Decay time

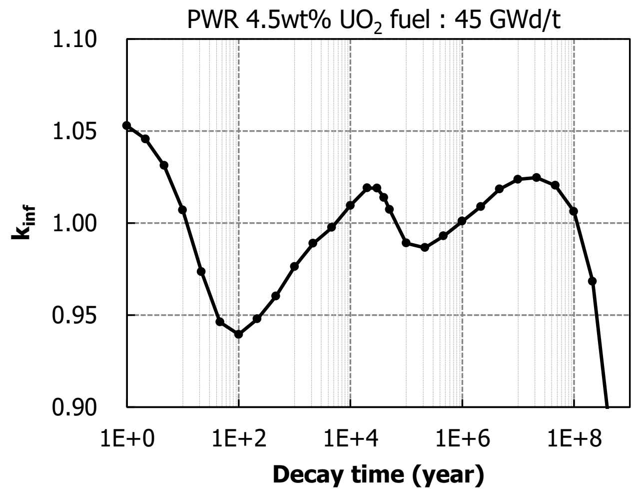
It should be noted that the neutron multiplication factor has a wide range over the long-term time frame of geological disposal because fissile or absorber nuclides can increase or decrease by the radioactive decay. Figure C.3 shows the examples for 30 GWd/t and 45 GWd/t burned fuels. The infinite multiplication factor, as shown in Figure C.3, was calculated for the infinite pin-cell geometry model applying almost all the important nuclides, which are listed in Table C.4, to understand the time dependence of the multiplication factor. For both cases, the neutron multiplication factor has two peaks around 30 000 and 20 million years. Based on this, 0, 30 000, and 20 million years are selected in this benchmark.

In the used fuel case of this benchmark, the concept of burn-up credit is taken into account and the burned fuel composition at each position in the fuel assembly is assumed to be uniform. To prepare the burned fuel compositions, burn-up calculations were conducted by ORIGEN2.2 [3,4] adopting ORLIBJ40 [5] cross-section library. In this benchmark, 13 actinides and 15 fission products are adopted for the criticality calculation, which are listed in Table C.5. These are selected in the past burn-up credit criticality benchmarks by NEA [6]. In addition to that, ^{233}U is selected considering the accumulation of ^{233}U by the long-term radioactive decay. The number of densities of used fuels burned at 30 GWd/t and 45 GWd/t is shown in Tables C.6 and C.7.

Figure C.3 Neutron multiplication factor against decay time



(a) 30 GWd/t



(b) 45 GWd/t

Source: JAEA, 2019.

Table C.4 Nuclide list used in the calculation of infinite multiplication factor

	Nuclide list
20 Actinides	^{233}U, ^{234}U, ^{235}U, ^{236}U, ^{238}U, ^{237}Np, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu, ^{242}Pu, ^{241}Am, ^{242}Am, ^{242m}Am, ^{243}Am, ^{242}Cm, ^{243}Cm, ^{244}Cm, ^{245}Cm, ^{246}Cm
47 Fission products	^{83}Kr, ^{95}Mo, ^{97}Mo, ^{98}Mo, ^{99}Tc, ^{101}Ru, ^{103}Ru, ^{103}Rh, ^{105}Rh, ^{105}Pd, ^{107}Pd, ^{108}Pd, ^{109}Ag, ^{113}Cd, ^{115}In, ^{131}Xe, ^{133}Xe, ^{135}Xe, ^{133}Cs, ^{134}Cs, ^{135}Cs, ^{141}Pr, ^{143}Pr, ^{143}Nd, ^{145}Nd, ^{147}Nd, ^{147}Pm, ^{148}Pm, ^{148m}Pm, ^{149}Pm, ^{147}Sm, ^{148}Sm, ^{149}Sm, ^{150}Sm, ^{151}Sm, ^{152}Sm, ^{153}Eu, ^{154}Eu, ^{155}Eu, ^{156}Eu, ^{152}Gd, ^{154}Gd, ^{155}Gd, ^{156}Gd, ^{157}Gd, ^{158}Gd, ^{160}Gd

Source: JAEA, 2019.

Table C.5 Nuclide list used in the criticality calculation in this benchmark

	Nuclide list
13 Actinides	^{233}U, ^{234}U, ^{235}U, ^{236}U, ^{238}U, ^{237}Np, ^{238}Pu, ^{239}Pu, ^{240}Pu, ^{241}Pu, ^{242}Pu, ^{241}Am, ^{243}Am
15 Fission products	^{95}Mo, ^{99}Tc, ^{101}Ru, ^{103}Rh, ^{109}Ag, ^{133}Cs, ^{147}Sm, ^{149}Sm, ^{150}Sm, ^{151}Sm, ^{152}Sm, ^{143}Nd, ^{145}Nd, ^{153}Eu, ^{155}Gd

Source: JAEA, 2019.

Table C.6 Number density of 30 GWd/t burned fuel

30 G Wd/t (#/barn/cm)			
Decay time (year)	0.00E+00	3.00E+04	2.00E+07
Actinide			
^{233}U	3.5590E-11	3.1581E-07	4.0816E-09
^{234}U	6.3908E-08	2.4520E-06	1.1776E-06
^{235}U	4.4013E-04	5.1974E-04	5.6688E-04
^{236}U	1.0735E-04	1.4487E-04	8.1136E-05
^{238}U	2.1492E-02	2.1492E-02	2.1431E-02
^{237}Np	8.5259E-06	3.4994E-05	5.4966E-08
^{238}Pu	2.2935E-06	0.0000E+00	0.0000E+00
^{239}Pu	1.3530E-04	5.8346E-05	2.1611E-15
^{240}Pu	3.9089E-05	1.6514E-06	1.3861E-14
^{241}Pu	2.5945E-05	1.4039E-12	0.0000E+00
^{242}Pu	5.9083E-06	5.5910E-06	0.0000E+00
^{241}Am	6.2531E-07	4.2499E-11	0.0000E+00
^{243}Am	8.4105E-07	5.01147E-08	6.6060E-16
Fission product			
^{95}Mo	3.4410E-05	4.1747E-05	4.1747E-05
^{99}Tc	4.1123E-05	3.7478E-05	0.0000E+00
^{101}Ru	3.8223E-05	3.8224E-05	3.8224E-05
^{103}Rh	2.1211E-05	2.3714E-05	2.3714E-05
^{109}Ag	2.6601E-06	2.6665E-06	2.6665E-06
^{133}Cs	4.3335E-05	4.3874E-05	4.3874E-05
^{147}Sm	2.3798E-06	1.0535E-05	1.0534E-05
^{149}Sm	1.1202E-07	1.6000E-07	1.6000E-07
^{150}Sm	9.4144E-06	9.4145E-06	9.4145E-06
^{151}Sm	4.8645E-07	0.0000E+00	0.0000E+00
^{152}Sm	3.5278E-06	3.5282E-06	3.5282E-06
^{143}Nd	3.1569E-05	3.2553E-05	3.2554E-05
^{145}Nd	2.4498E-05	2.4510E-05	2.4510E-05
^{153}Eu	3.3567E-06	3.3870E-06	3.3870E-06
^{155}Gd	1.9812E-09	2.0368E-07	2.0368E-07
Others			
^{16}O	4.5960E-02	4.5960E-02	4.5960E-02

Source: JAEA, 2019.

Table C.7 Number density of 45 GWd/t burned fuel

30 G Wd/t (#/barn/cm)			
Decay time (year)	0.00E+00	3.00E+04	2.00E+07
Actinide			
^{233}U	3.5120E-11	4.9070E-07	6.3435E-09
^{234}U	1.0024E-07	6.4456E-06	1.1636E-06
^{235}U	2.5992E-04	3.4617E-04	4.0208E-04
^{236}U	1.3269E-04	1.8831E-04	1.0563E-04
^{238}U	2.1227E-02	2.1227E-02	2.1176E-02
^{237}Np	1.4257E-05	5.4379E-05	8.5427E-08
^{238}Pu	6.2772E-06	0.0000E+00	0.0000E+00
^{239}Pu	1.4480E-04	6.3700E-05	5.9639E-14
^{240}Pu	5.6911E-05	2.4471E-06	7.8754E-14
^{241}Pu	3.9099E-05	1.3414E-11	0.0000E+00
^{242}Pu	1.5184E-05	1.4373E-05	0.0000E+00
^{241}Am	1.1751E-06	4.0607E-10	0.0000E+00
^{243}Am	3.2111E-06	1.9136E-07	1.8230E-14
Fission product			
^{95}Mo	5.2295E-05	5.9184E-05	5.9184E-05
^{99}Tc	5.8734E-05	5.3436E-05	0.0000E+00
^{101}Ru	5.6898E-05	5.6900E-05	5.6900E-05
^{103}Rh	2.9856E-05	3.2651E-05	3.2651E-05
^{109}Ag	4.8499E-06	4.8592E-06	4.8592E-06
^{133}Cs	6.0902E-05	6.1439E-05	6.1439E-05
^{147}Sm	3.8097E-06	1.2592E-05	1.2590E-05
^{149}Sm	1.0999E-07	1.6246E-07	1.6246E-07
^{150}Sm	1.4649E-05	1.4694E-05	1.4649E-05
^{151}Sm	5.6117E-07	0.0000E+00	0.0000E+00
^{152}Sm	4.5354E-06	4.5359E-06	4.5359E-06
^{143}Nd	4.1013E-05	4.1949E-05	4.1950E-05
^{145}Nd	3.4106E-05	3.4117E-05	3.4117E-05
^{153}Eu	5.6088E-06	5.6507E-06	5.6507E-06
^{155}Gd	3.7644E-09	3.8253E-07	3.8253E-07
Others			
^{16}O	4.5960E-02	4.5960E-02	4.5960E-02

Source: JAEA, 2019.

C.5 Benchmark cases

Fresh fuel case

The combinations of the water moderator and the three types of reflector materials are applied in the fresh fuel case. In addition, the condition that both moderator and reflector region are filled with SiO_2 containing water is applied for more realistic cases. A number of sets of the reflector thicknesses is applied in order to examine the influence of the reflector thickness. Table C.8 shows the calculation cases and the corresponding case IDs. The calculation cases for larger thickness of the wet SiO_2 and the water are omitted since the neutron multiplication factors remain unchanged. The total number of the first part of the benchmark is 19.

Table C.8 Calculation case and case ID for fresh fuel case

Moderator material	Reflector material	Reflector thickness						
		0 cm	10 cm	20 cm	40 cm	60 cm	90 cm	120 cm
H_2O	SiO_2 (dry)	zero	sd10	sd20	sd40	sd60	sd90	sd120
	SiO_2 (wet)		sw10	sw20	sw40	sw60	-	-
	H_2O		lw10	lw20	lw40	-	-	-
SiO_2 (wet)	SiO_2 (wet)	zeros	sw10s	sw20s	sw40s	sw60s	-	-

Source: JAEA, 2019.

Used fresh fuel case

Several representative reflector thicknesses are selected for the used fuel case adopting six different fuel compositions described in Section C.4. The calculation cases and the corresponding case IDs are shown in Table C.9. Each fuel composition is identified by the fuel ID “a” to “f”. The case IDs are determined by combining the fuel ID and the reflector ID, as shown in Table C.9.The total number of the second part of the benchmark is 48.

Table C.9 Calculation case and case ID for used fuel case

Fuel ID	Burnup	Decay time	Reflector material / Reflector thickness							
			0 cm	SiO_2 (dry)			SiO_2 (wet)		H_2O	
				10 cm	40 cm	120 cm	10 cm	40 cm	10 cm	40 cm
a	30 GWd/t	0 year	a-zero	a-sd10	a-sd40	a-sd120	a-sw10	a-sw40	a-lw10	a-lw40
b		30,000 year	b-zero	b-sd10	b-sd40	b-sd120	b-sw10	b-sw40	b-lw10	b-lw40
c		20 million year	c-zero	c-sd10	c-sd40	c-sd120	c-sw10	c-sw40	c-lw10	c-lw40
d	45 GWd/t	0 year	d-zero	d-sd10	d-sd40	d-sd120	d-sw10	d-sw40	d-lw10	d-lw40
e		30,000 year	e-zero	e-sd10	e-sd40	e-sd120	e-sw10	e-sw40	e-lw10	e-lw40
f		20 million year	f-zero	f-sd10	f-sd40	f-sd120	f-sw10	f-sw40	f-lw10	f-lw40

Source: JAEA, 2019.

C.6 Requested data

Fresh fuel case

The following data are requested for the fresh fuel cases. The definition of this data is described below the items:

i. effective neutron multiplication factor (k_{eff});

ii. reaction rates inside the reflector region for ^{16}O scattering, ^{28}Si scattering, ^{28}Si capture, ^{1}H scattering and ^{1}H capture;

iii. ratio of the absorption rate to the production rate in the system (similar to 1/kinf);

iv. thermal spectrum index in the fuel assembly region.

The reaction rates in the requested data (ii) are defined to be integrated over the reflector region and to be normalised by the production rate integrated over the whole system (i.e. neutron source in the system). The reaction rates of ^{16}O scattering, ^{28}Si scattering, ^{28}Si capture, ^{1}H scattering, and ^{1}H capture inside the reflector region are defined as follows:

$$R_s^{\mathrm{O-16}} = \frac{\iint_{V_R} \Sigma_s^{\mathrm{O-16}} \phi(\vec{r},E)dVdE}{P} \quad (1)$$

$$R_s^{\mathrm{Si\text{-}28}} = \frac{\iint_{V_R} \Sigma_s^{\mathrm{Si\text{-}28}} \phi(\vec{r},E)dVdE}{P} \quad (2)$$

$$R_c^{\mathrm{Si\text{-}28}} = \frac{\iint_{V_R} \Sigma_c^{\mathrm{Si\text{-}28}} \phi(\vec{r},E)dVdE}{P} \quad (3)$$

$$R_s^{\mathrm{H\text{-}1}} = \frac{\iint_{V_R} \Sigma_s^{\mathrm{H\text{-}1}} \phi(\vec{r},E)dVdE}{P} \quad (4)$$

$$R_c^{\mathrm{H\text{-}1}} = \frac{\iint_{V_R} \Sigma_c^{\mathrm{H\text{-}1}} \phi(\vec{r},E)dVdE}{P} \quad (5)$$

Where:

$$P = \iint_{V_{FA}+V_R} \nu\Sigma_f \phi(\vec{r},E)dVdE \cdot$$

Here, V_R and V_{FA} are the volume of reflector and fuel assembly, $\phi(\vec{r},E)$ is neutron flux, ν is the number of neutrons per fission and Σ_f^i, Σ_s^i and Σ_c^i are macroscopic fission, scattering and capture cross-section for nuclide i, respectively. Scattering cross-section means the total of elastic and inelastic scattering cross-sections.

The ratio of the absorption rate to the production rate in the requested data (iii) is defined as follows:

$$\frac{A}{P} = \frac{\iint_{V_{FA}+V_R} \Sigma_a \phi(\vec{r},E)dVdE}{\iint_{V_{FA}+V_R} \nu\Sigma_f \phi(\vec{r},E)dVdE} \quad (6)$$

Here, A is the absorption rate and P is the production rate in the whole system. This value could be used to calculate the probability of the neutron leakage from the system. The ratio of the leakage rate (L) to the production rate (P) calculated by the following equation is used for comparison purposes because this value is important to investigate the mechanism of the reflector effect.

$$\frac{L}{P} = \frac{1}{k_{eff}} - \frac{A}{P} \qquad (7)$$

This equation is derived from the following fundamental k_{eff} definition:

$$k_{eff} = \frac{P}{A+L} \qquad (8)$$

In this benchmark, the co-ordinator calculated the ratio of the leakage rate to the production rate (L/P) using the data from the participants.

The thermal spectrum index in the requested data (iv) is defined to be the ratio of the thermal flux to the total flux, where the boundary energy is set to be 0.625eV. The thermal spectrum index in the fuel assembly region is defined as follows:

$$SI_{th} = \frac{\phi_{thermal}}{\phi_{total}} = \frac{\int_{thermal}\int_{V_{FA}} \phi(\vec{r}, E)dVdE}{\int_{thermal+fast}\int_{V_{FA}} \phi(\vec{r}, E)dVdE} \qquad (9)$$

Here, V_{FA} involves all the components inside the fuel assembly (i.e. fuel pellets, cladding tubes, guide tubes and moderator regions).

Used fuel case

The following data is requested for the used fuel cases: effective neutron multiplication factor (k_{eff}).

C.7 Results and media

E-mails attaching Microsoft Excel file containing the results were sent to: nea-nsc-wpncs@jaea.go.jp

A recommended format of the Excel sheet is shown below. The Excel file was sent to the participants. If the Monte Carlo transport code was used, the statistical error should be included in the sheet for the k_{eff} results. In the case of missing results, “NODATA” should be mentioned in the format.

Line No.	Data
1	Date
2	Institute
3	Contact person
4	E-mail address or Telefax Number
5	Computer code
	---------- Fresh fuel case ----------

6	k_{eff} for case "zero"
7	k_{eff} for case "sd10"
8	k_{eff} for case "sd20"
9	k_{eff} for case "sd40"
10	k_{eff} for case "sd60"
11	k_{eff} for case "sd90"
12	k_{eff} for case "sd120"
13	k_{eff} for case "sw10"
14	k_{eff} for case "sw20"
15	k_{eff} for case "sw40"
16	k_{eff} for case "sw60"
17	k_{eff} for case "lw10"
18	k_{eff} for case "lw20"
19	k_{eff} for case "lw40"
20	k_{eff} for case "zeros"
21	k_{eff} for case "sw10s"
22	k_{eff} for case "sw20s"
23	k_{eff} for case "sw40s"
24	k_{eff} for case "sw60s"
25 to 41	Reaction rate of O-16 scattering, Si-28 scattering, Si-28 capture, H-1 scattering, H-1 capture in the same order for items 7 to 19, and 21 to 24 (save in sequential row)
42 to 60	Rate of absorption rate to production rate in the system (A/P) in the same order for items 6 to 24
61 to 79	Thermal spectrum index in the same order for items 6 to 24
	---------- Used fuel case ----------
80	k_{eff} for case "a-zero", "b-zero", "c-zero", "d-zero", "e-zero", "f-zero" (save in sequential row)
81	k_{eff} for case "a,b,c,d,e,f-sd10" (save in sequential row)
82	k_{eff} for case "a,b,c,d,e,f-sd40" (save in sequential row)
83	k_{eff} for case "a,b,c,d,e,f-sd120" (save in sequential row)
84	k_{eff} for case "a,b,c,d,e,f-sw10" (save in sequential row)
85	k_{eff} for case "a,b,c,d,e,f-sw40" (save in sequential row)
86	k_{eff} for case "a,b,c,d,e,f-lw10" (save in sequential row)
87	k_{eff} for case "a,b,c,d,e,f-lw40" (save in sequential row)
88	Please describe your analysis environment here. The description should include:
	- Institute and country
	- Participants
	- Neutron data library
	- Neutron data processing code or method
	- Number of neutron energy group

	- Description of your code system
	- Geometry modeling
	- Omitted nuclides, if any
	- Employed convergence limit or statistical errors for eigenvalue calculations
	- Other related information
	- References to your code system or library, if any

C.8 Schedule

Deadline for participants to provide their results: May 2015.

Deadline for co-ordinators to compile the results into tables and/or figures: August 2015.

Deadline for co-ordinators to send the draft report to the participants: January 2016.

C.9 References

[1] Yamamoto, T. et al. (2002), "Benchmark problem suite for reactor physics study of LWR next generation fuels", *J. Nucl. Sci. Technol*., Vol. 37, No. 8, pp. 900-912.

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[3] Croff, A.G. (1983), "ORIGEN2: A versatile computer code for calculating the nuclide compositions and characteristics of nuclear materials", *Nucl. Sci.Technol*. Vol. 62, p.335.

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[6] Takano, M. (1994), *OECD/NEA Burn-up Credit Criticality Benchmark – Result of Phase-1A,* JAERI-M 94-003.