APPENDIX

Appendix A

The size distribution of CeO_2 particles evaluated
from transmission electron microscope(TEM) images.

1. <u>Method for calculation of particle size from TEM images</u>

From scale length 1.6 cm = 50 nm

CeO_2 particle had diameter of 0.4 cm

Then length of 1.6 cm = length of 50 nm

Particle diameter length of 0.4 cm = length of $\frac{50 \times 0.4}{1.6}$ nm

= 12.5 nm

Appendix Table A Particle size evaluated from TEM images

1) Microemulsion method (method 1) using PE4LE as a surfactant.

Particle size (nm)	Cerium sources					
	$Ce(NO_3)_3 \cdot 6H_2O$		$(NH_4)_2Ce(NO_3)_6$		$CeCl_3 \cdot 7H_2O$	
	Amount of CeO_2 particles	Frequency (%)	Amount of CeO_2 particles	Frequency (%)	Amount of CeO_2 particles	Frequency (%)
<3.1	1	1.492537	-	-	-	
6.2	9	13.43284	10	16.66667	11	10.89109
9.4	22	32.83582	20	33.33333	15	14.85149
12.5	23	34.32836	24	40.00000	63	62.37624
>15.6	12	17.91044	6	10.00000	12	11.88119
	Total = 67	Total = 100	Total = 60	Total = 100	Total = 101	Total = 100

2) Microemulsion method (method 1) using Brij96V as a surfactant.

Particle size (nm)	Cerium sources					
	$Ce(NO_3)_3 \cdot 6H_2O$		$(NH_4)_2Ce(NO_3)_6$		$CeCl_3 \cdot 7H_2O$	
	Amount of CeO_2 particles	Frequency (%)	Amount of CeO_2 particles	Frequency (%)	Amount of CeO_2 particles	Frequency (%)
<3.9	4	3.252033	2	2.702703	-	-
5.2	6	4.878049	9	12.16216	-	-
6.5	13	10.56911	15	20.27027	-	-
7.8	17	13.82114	19	25.67568	30	41.66667
>9.1	83	67.47967	28	39.18919	42	58.33333
	Total = 123	Total = 100	Total = 74	Total = 100	Total = 72	Total = 100

3) Microemulsion method (method 1) using CTAB as a surfactant and butanol as a cosurfactant.

Particle size (nm)	Cerium sources					
	$Ce(NO_3)_3{\cdot}6H_2O$		$(NH_4)_2Ce(NO_3)_6$		$CeCl_3{\cdot}7H_2O$	
	Amount of CeO_2 particles	Frequency (%)	Amount of CeO_2 particles	Frequency (%)	Amount of CeO_2 particles	Frequency (%)
<3.9	17	15.59633	82	23.29545	26	16.14907
5.2	22	20.18349	85	24.14773	31	19.25466
6.5	32	29.35780	86	24.43182	26	16.14907
7.8	19	17.43119	56	15.90909	23	14.28571
>9.1	19	17.43119	43	12.21591	58	36.02484
	Total = 109	Total = 100	Total = 352	Total = 100	Total = 161	Total = 100

4) Combined methods of homogeneous precipitation and microemulsion (method 2) using PE4LE as a surfactant.

Particle size (nm)	Cerium sources					
	$Ce(NO_3)_3{\cdot}6H_2O$		$(NH_4)_2Ce(NO_3)_6$		$CeCl_3{\cdot}7H_2O$	
	Amount of CeO_2 particles	Frequency (%)	Amount of CeO_2 particles	Frequency (%)	Amount of CeO_2 particles	Frequency (%)
<3.9	-	-	37	20.21858	4	2.352941
5.2	8	11.59420	40	21.85792	17	10.00000
6.5	28	40.57971	44	24.04372	30	17.64706
7.8	19	27.53623	18	9.836066	29	17.64706
>9.1	14	20.28986	44	24.04376	90	52.94118
	Total = 69	Total = 100	Total = 183	Total = 100	Total = 170	Total = 100

5) Combined methods of homogeneous precipitation and microemulsion (method 2) using CTAB as a surfactant and butanol as a cosurfactant.

Particle size (nm)	Cerium sources					
	$Ce(NO_3)_3{\cdot}6H_2O$		$(NH_4)_2Ce(NO_3)_6$		$CeCl_3{\cdot}7H_2O$	
	Amount of CeO_2 particles	Frequency (%)	Amount of CeO_2 particles	Frequency (%)	Amount of CeO_2 particles	Frequency (%)
<3.9	77	30.31496	18	28.12500	20	16.52893
5.2	82	32.28346	38	59.37500	16	13.22314
6.5	62	24.40945	-	-	32	26.44628
7.8	15	5.905512	6	9.375000	13	10.74380
>9.1	18	7.086614	2	3.125000	40	33.05782
	Total = 254	Total = 100	Total = 64	Total = 100	Total = 121	Total = 100

6) Mixing of two microemulsions (method 3) using PE4LE as a surfactant.

Particle size (nm)	Cerium sources					
	$Ce(NO_3)_3{\cdot}6H_2O$		$(NH_4)_2Ce(NO_3)_6$		$CeCl_3{\cdot}7H_2O$	
	Amount of CeO_2 particles	Frequency (%)	Amount of CeO_2 particles	Frequency (%)	Amount of CeO_2 particles	Frequency (%)
<3.9	17	10.36585	11	9.909910	-	-
5.2	25	15.24390	26	23.42342	-	-
6.5	38	23.17073	23	20.72072	11	14.10256
7.8	33	20.12195	23	20.72072	52	66.66667
>9.1	51	31.09756	28	25.22523	15	19.23077
	Total = 164	Total = 100	Total = 111	Total = 100	Total = 78	Total = 100

7) Mixing of two microemulsions (method 3) using CTAB as a surfactant and butanol as a cosurfactant.

Particle size (nm)	Cerium sources					
	$Ce(NO_3)_3{\cdot}6H_2O$		$(NH_4)_2Ce(NO_3)_6$		$CeCl_3{\cdot}7H_2O$	
	Amount of CeO_2 particles	Frequency (%)	Amount of CeO_2 particles	Frequency (%)	Amount of CeO_2 particles	Frequency (%)
<3.9	37	48.68421	131	71.97802	25	16.77852
5.2	17	22.36842	35	19.23077	38	25.50336
6.5	9	11.84211	10	5.494505	36	24.16107
7.8	7	9.210526	6	3.296703	14	9.395973
>9.1	6	7.894737	-	-	36	24.16107
	Total = 76	Total = 100	Total = 182	Total = 100	Total = 149	Total = 100

Appendix B

Calculation of average particle size, standard deviation, standard error of mean, and percent standard error of mean

1. <u>Calculation of average particle size, standard deviation, standard error of mean, and percent standard error of mean (Apinya, 1998)</u>

1.1 The average particle size, $\bar{d}_n$ was calculated as follows:

$$\bar{d}_n = \frac{\Sigma(d_i)(n_i)}{n_t}$$

Where, d_i = Particle size, nm

n_i = Amount of CeO_2 particles in each size.

n_t = Total collected particles.

Example from Appendix Table A5

Average particle size of CeO_2

$$= \frac{(2.6)(4) + (3.9)(73) + (5.2)(82) + (6.5)(62) + (7.8)(15) + (9.1)(3) + (10.4)(7) + (13.0)(8)}{254}$$

= 5.7 nm

1.2 The number standard deviation δ_n was calculated as follows:

$$\delta_n = \sqrt{\frac{\Sigma\left(d_i - \bar{d}_n\right)^2}{n_t - 1}}$$

1.3 The standard error of mean, S.E. was calculated as follows:

$$S.E. = \frac{\delta_n}{\sqrt{n_t}}$$

1.4 The percent standard error of mean, %S.E. was calculated as follows:

$$\%S.E. = \frac{S.E.\ x\ 100}{\bar{d}_n}$$

Appendix Table B Summarize the calculation of average particle size, standard deviation, standard error of mean, and percent standard error of mean.

Method	Cerium source	Surfactant	Average particle size (nm)	δ_n	S.E.	%S.E
Method 1	$Ce(NO_3)_3 \cdot 6H_2O$	PE4LE	11.1	3.17	0.39	3.49
	$(NH_4)_2Ce(NO_3)_6$		9.4	2.24	0.30	3.21
	$CeCl_3 \cdot 7H_2O$		11.5	2.68	0.27	2.32
	$Ce(NO_3)_3 \cdot 6H_2O$	Brij96V	10.2	3.52	0.32	3.11
	$(NH_4)_2Ce(NO_3)_6$		8.2	2.41	0.28	3.42
	$CeCl_3 \cdot 7H_2O$		11.2	2.28	0.42	3.72
	$Ce(NO_3)_3 \cdot 6H_2O$	CTAB (used butanol as cosurfactant)	6.7	2.12	0.20	3.03
	$(NH_4)_2Ce(NO_3)_6$		6.1	1.96	0.10	1.72
	$CeCl_3 \cdot 7H_2O$		8.1	4.44	0.35	4.32
Method 2	$Ce(NO_3)_3 \cdot 6H_2O$	PE4LE	7.9	1.98	0.28	3.57
	$(NH_4)_2Ce(NO_3)_6$		7.2	4.28	0.32	4.39
	$CeCl_3 \cdot 7H_2O$		9.2	3.51	0.27	2.93
	$Ce(NO_3)_3 \cdot 6H_2O$	CTAB (used butanol as cosurfactant)	5.7	2.01	0.13	2.22
	$(NH_4)_2Ce(NO_3)_6$		4.9	1.80	0.24	4.88
	$CeCl_3 \cdot 7H_2O$		7.7	3.01	0.27	3.56
Method 3	$Ce(NO_3)_3 \cdot 6H_2O$	PE4LE	7.6	4.09	0.32	4.20
	$(NH_4)_2Ce(NO_3)_6$		7.1	2.28	0.22	3.05
	$CeCl_3 \cdot 7H_2O$		8.8	1.39	0.16	1.79
	$Ce(NO_3)_3 \cdot 6H_2O$	CTAB (used butanol as cosurfactant)	5.1	2.29	0.26	5.16
	$(NH_4)_2Ce(NO_3)_6$		4.1	1.25	0.09	2.27
	$CeCl_3 \cdot 7H_2O$		6.7	2.31	0.19	2.82