

## Supporting Information

# Hybrid Nanogels by Encapsulation of Lanthanide-doped LaF<sub>3</sub> Nanoparticles as Elemental Tags for Detection by Atomic Mass Spectrometry

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### 1. Synthesis of LaF<sub>3</sub>:Ln NPs.

To synthesize LaF<sub>3</sub>:Ln NPs, a solution of the ligands (AEP and EGMAP; overall stabilizer amount was kept constant at 1.08 mmol for all samples) in 10 ml water was neutralized to pH = 6.7 with 1.5 M NH<sub>3</sub>·H<sub>2</sub>O. To this solution a mixture of La(NO<sub>3</sub>)<sub>3</sub>·6H<sub>2</sub>O (0.50 g, 1.17 mmol) and Ln(NO<sub>3</sub>)<sub>3</sub>·xH<sub>2</sub>O (where Ln: Eu (x=5), Tb (x=5), Pr (x=6) or Gd (x=6)) in 10 ml of water was added to form the La/Ln-AEP/EGMAP complex at room temperature and then stirred at 500 rpm for 10 minutes. To the clear solution, NaF (0.13 g, 3 mmol) in 13 ml water was added drop-wise via a feed pump at 10 drops/min. The mixed solution was further stirred for 18 hours (at 500 rpm), to yield a clear solution. A detailed description of the reaction recipes are given in Table S1. These experiments were carried out to determine the effect of ligand mixtures on the synthesis and in Table S2 to show the synthesis with different dopant ions and fixed stabilizer concentrations. The NP solutions were purified by dialysis against MilliQ-water at room temperature for 3 days (water was changed three times a day) using a dialysis bag (1 K Dalton Spectra/Pro 7 Dialysis Membranes).

**Table S1.** Ingredients used for the synthesis of LaF<sub>3</sub>:Eu NPs with variable ligand mixtures<sup>a</sup>.

Sample	AEP		EGMAP		X <sub>EGMAP</sub> <sup>c</sup>
	[mmol]	[g]	[mmol]	[g]	[mol%]
LaF <sub>3</sub> :Eu0	1.08	0.153	-	-	0
LaF <sub>3</sub> :Eu5	1.03	0.145	0.05	0.011	5
LaF <sub>3</sub> :Eu10	0.97	0.138	0.11	0.023	10
LaF <sub>3</sub> :Eu20	0.87	0.122	0.22	0.046	20
LaF <sub>3</sub> :Eu33 <sup>b</sup>	0.72	0.102	0.36	0.076	33

<sup>a</sup> The amount of lanthanides was kept constant at 1.17 mmol (500 mg) La(NO<sub>3</sub>)<sub>3</sub>·6H<sub>2</sub>O and 0.16 mmol (70 mg) Eu(NO<sub>3</sub>)<sub>3</sub>·5H<sub>2</sub>O.

<sup>b</sup> LaF<sub>3</sub>:Eu33 - Eu-doped LaF<sub>3</sub> NPs with a theoretical mixture of AEP/EGMAP = 2/1 (mol/mol) on the particle surface.

<sup>c</sup> X<sub>EGMAP</sub>: mole % EGMAP in the EGMAP/AEP mixture used in the synthesis of the LaF<sub>3</sub>:Eu nanoparticles.

**Table S2.** Ingredients used for the synthesis of LaF<sub>3</sub>:Ln NPs doped with different Ln ions<sup>a</sup>.

Sample	La(NO <sub>3</sub> ) <sub>3</sub> ·6H <sub>2</sub> O		Ln(NO <sub>3</sub> ) <sub>3</sub> ·xH <sub>2</sub> O				x <sub>Ln</sub> <sup>c</sup>
	[mmol]	[g]	Ln =	x =	[mmol]	[g]	[mol%]
LaF <sub>3</sub> :Eu33 <sup>b</sup>	1.15	0.5	Eu	5	0.16	0.068	10
LaF <sub>3</sub> :Tb33	1.15	0.5	Tb	5	0.16	0.070	10
LaF <sub>3</sub> :Gd33	1.15	0.5	Gd	6	0.16	0.072	10
LaF <sub>3</sub> :Pr33	1.15	0.5	Pr	6	0.16	0.070	10

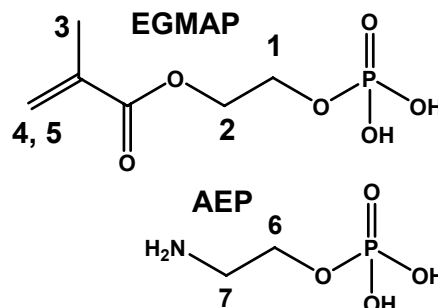
<sup>a</sup> The amount of lanthanides was kept constant at 0.72 mmol (102 mg) AEP and 0.36 mmol (76 mg) EGMAP.

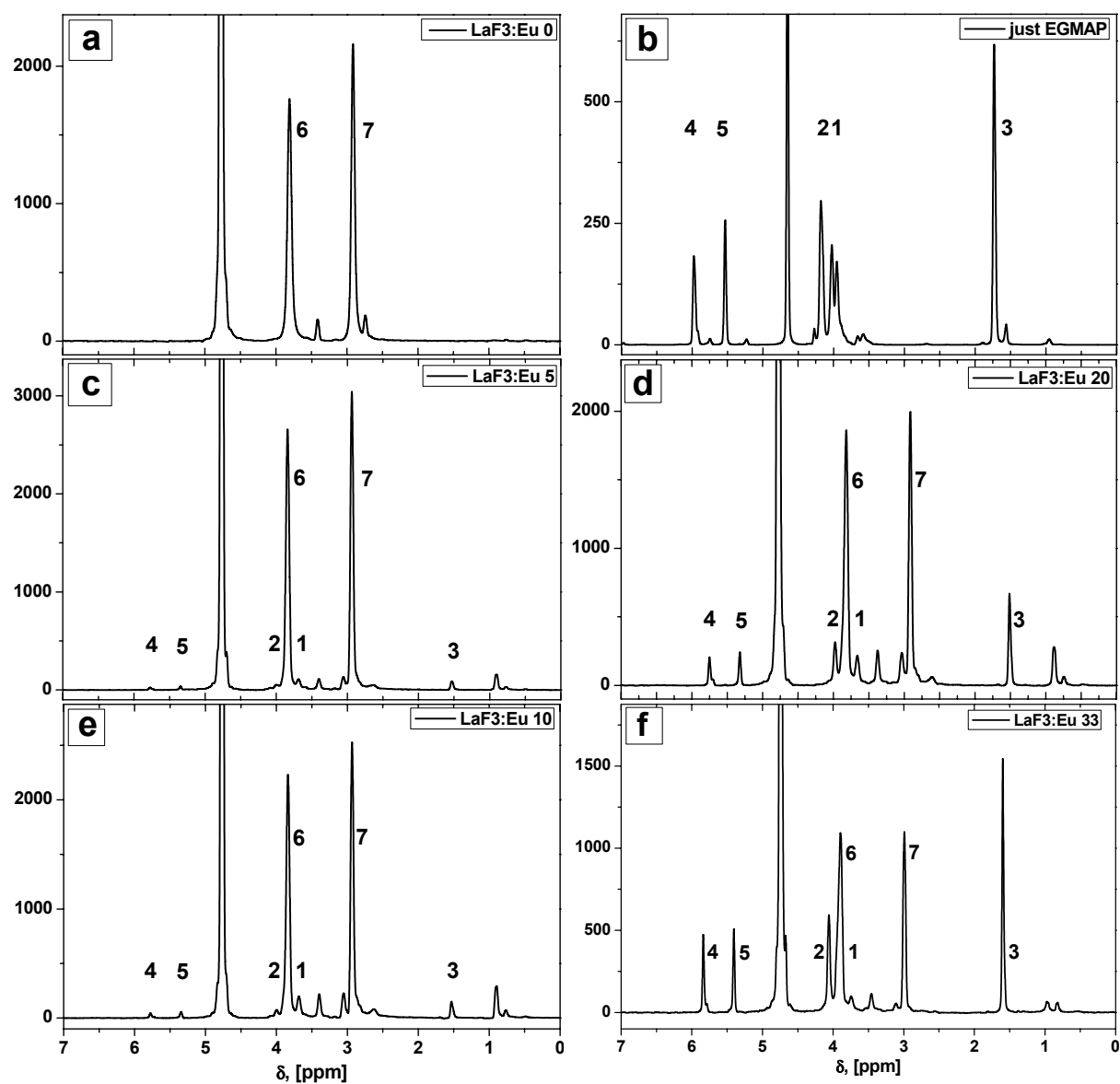
<sup>b</sup> LaF<sub>3</sub>:Eu33: Eu-doped LaF<sub>3</sub> NPs with a theoretical mixture of AEP/EGMAP = 2/1 (mol/mol) on the particle surface.

<sup>c</sup> x<sub>Ln</sub>: mole fraction of Ln in the La/Ln mixture used in the synthesis of the LaF<sub>3</sub>:Ln nanoparticles.

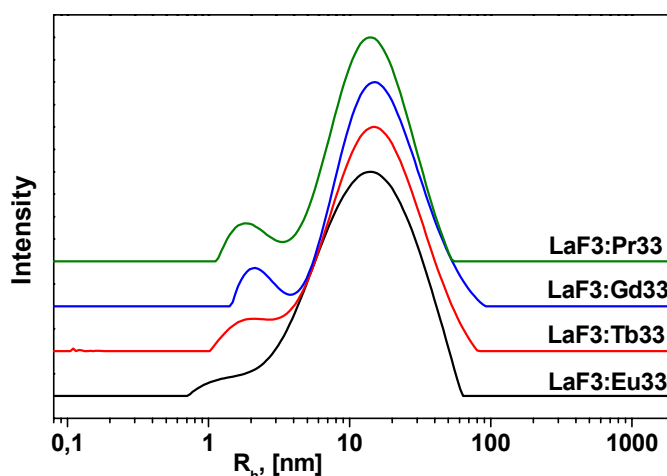
#### *NMR studies of LaF<sub>3</sub>:Eu NPs with different stabilizer ratios*

The spectrum (a) in Figure S1 corresponds to LaF<sub>3</sub>:Eu NPs with just AEP ligands on the surface. The proton signals in Figure S1b-f labeled **4** and **5** (at 5.8 and 5.4 ppm, respectively) correspond to the vinyl protons (CH<sub>2</sub>=CR<sub>2</sub>) of EGMAP, the signal labeled **3** at 1.6 ppm corresponds to the protons of the CH<sub>3</sub> of EGMAP, whereas the signals labeled **7** at 3.0 ppm correspond to the N-CH<sub>2</sub>-C protons of AEP. We obtain the ratio of EGMAP to AEP by setting the integration of the proton peaks **4** + **5** from EGMAP to 2.0 or by setting and comparing these values to the integration of the 3H signal for proton **7** of AEP.





**Figure S1.**  $^1\text{H}$  NMR spectra at 400 MHz of  $\text{LaF}_3:\text{Eu}$  nanoparticles (15 mg/mL) dissolved in  $\text{D}_2\text{O}/\text{DCl}$  (a, c-f) and (b) in  $\text{D}_2\text{O}$ . Spectra show proton shifts of (a) AEP-stabilized nanoparticles and NPs with mixed ligands (c) with theoretical 5 mol %, (e) 10 mol %, (d) 20 mol % and (f) 33 mol % EGMAP on the particle surface. (b) EGMAP itself in  $\text{D}_2\text{O}$  in absence of nanoparticles.

**Particle size of lanthanide doped LaF<sub>3</sub> NPs**

**Figure S2.** CONTIN plots of LaF<sub>3</sub>:Ln nanoparticles (doped with 10 mol% Eu, Tb, Pr, Gd) with theoretical 33 mol% EGMAP, measured by DLS,  $c_{\text{NPs}} = 5$  mg/ml in water, filtered with a 200 nm Nylon filter, maximum intensity normalized to 1.

**2. Synthesis of Nanogels****Nanogels containing just PAAEM and PVCL**

Nanogels were synthesized by placing appropriate amounts of monomers (VCL, AAEM, OEGMA, overall monomer concentration was set to 103 mmol/l for all samples, VCL:AAEM = 7.0 [mol:mol] for all samples), crosslinker (BIS, 2.5 mol% with respect to the total monomer concentration) into a 100 ml 2-neck round-bottom flask. The mixture was stirred at 150 rpm using a mechanical stirrer with a Teflon blade. The ingredients dissolved after addition of deionized water under stirring and with a N<sub>2</sub> flow at 50 °C. The LaF<sub>3</sub>:Ln NP aqueous solution was then added drop-wise to the mixture and stirred 30 more minutes at 50 °C. After increase of the temperature to 70°C and equilibrating for 15 min under a nitrogen flow, the aqueous initiator solution (AMPA, 30.5 mmol/l in 2 ml water, 1.2 mol% with respect to the total monomer concentration) was added at once into the reaction vessel, and the polymerization was carried out for 8 hours. The reaction recipes are presented in Table S3.

**Table S3.** Ingredients used for the synthesis of hybrid nanogels with variable polymer composition in presence of NPs with variable ligand mixtures, dopant, and nanoparticle mixtures.<sup>a</sup>

Sample	LaF <sub>3</sub> :Ln <sup>c</sup>		Sample	LaF <sub>3</sub> :Eu/ LaF <sub>3</sub> :Tb <sup>f</sup>	
	NP-sample	[mg]		[wt%/wt%]	[mg/mg]
NG-4-Eu-0 <sup>b</sup>	LaF <sub>3</sub> :Eu-0	32	NG-4-Eu-OEG-0 <sup>c</sup>	100/0	32/0
NG-4-Eu-5 <sup>b</sup>	LaF <sub>3</sub> :Eu-5	32	NG-4-Eu-OEG-0.5 <sup>c</sup>	100/0	32/0
NG-4-Eu-10 <sup>b</sup>	LaF <sub>3</sub> :Eu-10	32	NG-4-Eu-OEG-1.0 <sup>c</sup>	100/0	32/0
NG-4-Eu-20 <sup>b</sup>	LaF <sub>3</sub> :Eu-20	32	NG-4-Eu-OEG-2.0 <sup>c</sup>	100/0	32/0
NG-4-Eu-33 <sup>b</sup>	LaF <sub>3</sub> :Eu-33	32	NG-4-Eu/Tb-100/0 <sup>d</sup>	100/0	32/0
NG-4-Tb-33 <sup>b</sup>	LaF <sub>3</sub> :Tb-33	32	NG-4-Eu/Tb-75/25 <sup>d</sup>	75/25	25/7
NG-4-Gd-33 <sup>b</sup>	LaF <sub>3</sub> :Gd-33	32	NG-4-Eu/Tb-50/50 <sup>d</sup>	50/50	16/16
NG-4-Pr-33 <sup>b</sup>	LaF <sub>3</sub> :Pr-33	32	NG-4-Eu/Tb-25/75 <sup>d</sup>	25/75	7/25
			NG-4-Eu/Tb-0/100 <sup>d</sup>	0/100	0/32

<sup>a</sup> The amount of nanoparticles in the reaction mixtures was 4 wt % based upon total monomer.

<sup>b</sup> Each reaction also contained VCL (626 mg; 4.5 mmol), AAEM (140 mg; 0.65 mmol), BIS (20 mg; 0.13 mol), AMPA (16.6 mg; 0.06 mmol) in water (50 g, including the NP solution).

<sup>c</sup> Recipes for these syntheses are presented in Table S1 in supporting information. For these synthesis the mole ratio of VCL/AAEM = 7.0.

<sup>d</sup> Each reaction also contained VCL (615 mg; 4.42 mmol), AAEM (135 mg; 0.63 mmol), OEGMA (54 mg; 0.1 mmol), BIS (20 mg; 0.13 mmol), AMPA (16.6 mg; 0.06 mmol) in water (50 g) which includes the NP solution.

<sup>e</sup> The dry weight of NPs present in 4 g aqueous solution (calculated from the weight of the NP solution added and its solids content).

<sup>f</sup> Added amount of dry LaF<sub>3</sub>:Eu and LaF<sub>3</sub>:Tb NPs (values calculated out of weight and solids content of the NP-solutions) and corresponding ratio between them in the reaction mixture.

**Nanogels additionally containing OEG**

Nanogels were synthesized by placing appropriate amounts of monomers into a 100 ml 2-neck round-bottom flask: (VCL, AAEM, OEGMA, overall monomer concentration was set constant to 103 mmol/l for all samples, VCL:AAEM = 7.0 [mol/mol] for all samples), crosslinker (BIS, 2.5 mol% with respect to the total monomer concentration). The mixture was stirred using a mechanical stirrer with Teflon blade at 150 rpm. The ingredients dissolved after addition of deionized water under stirring and with a N<sub>2</sub> flow at 50 °C. The LaF<sub>3</sub>:Ln NP aqueous solution was then added drop-wise to the mixture and stirred 30 more minutes at 50 °C. After increasing the temperature to 70°C and equilibrating for 15 min under a nitrogen flow, we added the aqueous initiator solution (AMPA, 30.5 mmol/l in 2 ml water, 1.2 mol% with respect to the total monomer concentration) at once into the reaction vessel, and the polymerization was carried out for 8 hours. Detailed reaction recipes for samples NG-4-Eu-OEG-0 to NG-4-Eu-OEG-2.0 are given in Table S4.

**Table S4.** Ingredients used for the synthesis of hybrid nanogels in the presence of different amounts of OEGMA<sup>a</sup>.

Sample	VCL, [mg]	AAEM, [mg]	OEGMA, [mg]	X <sub>OEG</sub> <sup>b</sup> , [mol%]	BIS, [mg]	AMPA, [mg]	H <sub>2</sub> O <sup>c</sup> , [g]	LaF <sub>3</sub> :Eu <sup>d</sup> [mg]
NG-4-Eu-OEG-0	626	140	-	0	20	16.6	50	32
NG-4-Eu-OEG-0.5	624	137	13.6	0.5	20	16.6	50	32
NG-4-Eu-OEG-1.0	620	136	27.1	1.0	20	16.6	50	32
NG-4-Eu-OEG-2.0	615	135	54.3	2.0	20	16.6	50	32

<sup>a</sup> LaF<sub>3</sub>:Eu33 NPs (fixed stabilizer concentration); NPs concentration in nanogels 4 wt.-%

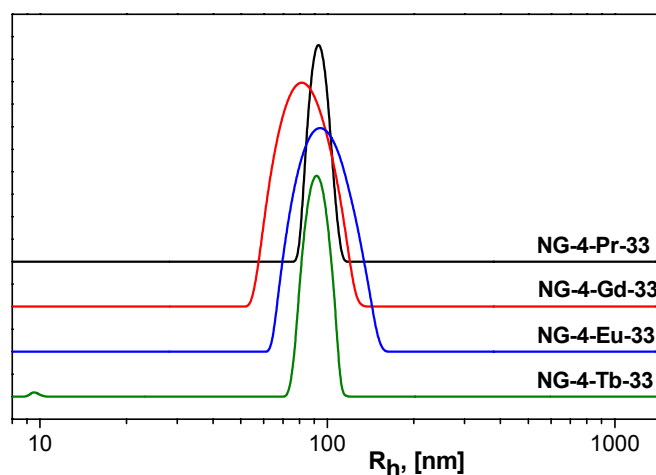
<sup>b</sup> Mole fraction of OEGMA in the reaction mixture with respect to the total monomer concentration.

<sup>c</sup> Final content of water in the reaction mixture after addition of all components.

<sup>d</sup> Added amount of dry NPs in 4 g water (values calculated out of weight and SC of the NP-solution).

**Nanogel size of samples with LaF<sub>3</sub>:Ln NPs and different dopant ions**

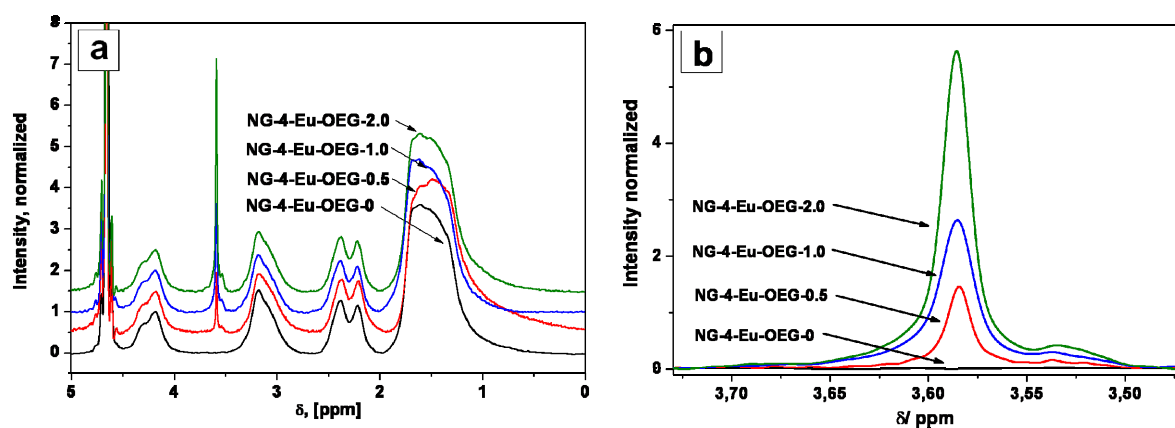
CONTIN plots are presented in Figure S1 of hybrid nanogels with different incorporated LaF<sub>3</sub>:Ln nanoparticles. These show monomodal and symmetric size distributions for all samples. All samples have  $R_h \approx 90$  nm.



**Figure S3.** CONTIN plots of the size distribution of the hybrid nanogels with incorporated (bottom to top) Tb-, Eu-, Gd- and Pr- doped LaF<sub>3</sub> nanoparticles at 20 °C.

**Incorporation of OEG chains in the nanogel structure**

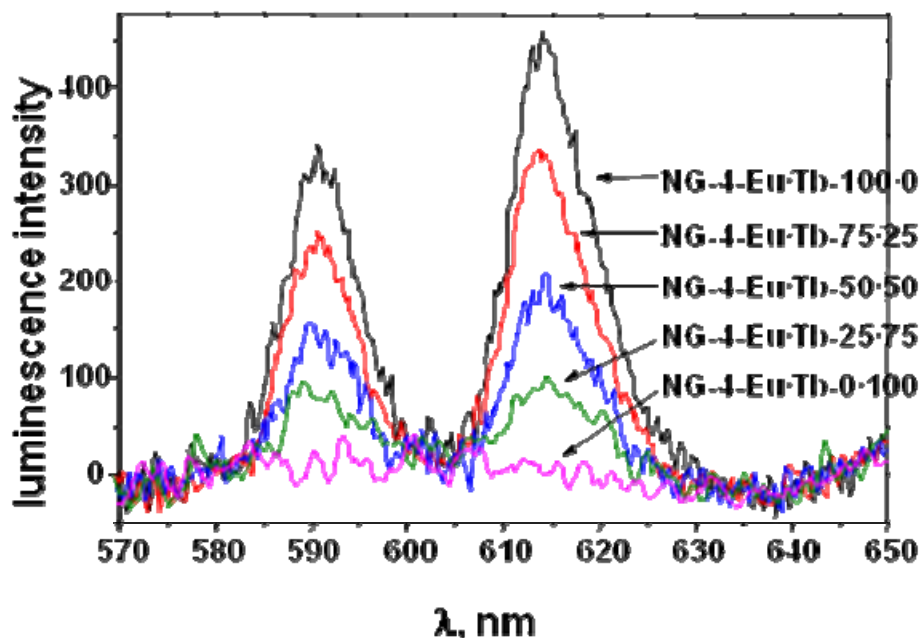
The incorporation of short PEG chains into the structure of the nanogels could be monitored using proton NMR. Figure S4a gives the spectra of nanogels with and without OEG normalized to the constant content of protons in the polymer backbone. Figure S4b shows the peaks for the protons of the OEG groups. Integration of the peaks at 3.58 ppm gives the OEG content of the samples NG-4-Eu-OEG-0/NG-4-Eu-OEG-0.5/NG-4-Eu-OEG-1.0/NG-4-Eu-OEG-2.0 = 0/1.0/2.3/4.0. These values are very close to the theoretical values based upon the ratio of the reactants.



**Figure S4.** (a) NMR shifts of nanogel-composite samples NG-4-Eu-OEG-0 to NG-4-Eu-OEG-2.0 with different OEG contents and (b) enhanced NMR spectrum of the shift of OEG protons at  $\delta = 3.58$  ppm.

**Encapsulation of NPs mixtures****Table S5.** Theoretical and experimental weight ratios of LaF<sub>3</sub>:Eu and LaF<sub>3</sub>:Tb nanoparticles incorporated into the nanogels

Sample	Theoretical ratio	Experimental ratio (ICP-MS)
	LaF <sub>3</sub> :Eu : LaF <sub>3</sub> :Tb [wt%:wt%]	LaF <sub>3</sub> :Eu : LaF <sub>3</sub> :Tb [wt%:wt%]
NG-4 Eu 100	100 : 0	100:0
NG-4 Eu/Tb 75/25	75 : 25	73.5 : 26.5
NG-4 Eu/Tb 50/50	50 : 50	48.5 : 51.5
NG-4 Eu/Tb 25/75	25 : 75	25.1 : 74.9
NG-4 Tb 100	0 : 100	0 : 100

**Figure S5.** PL spectra of core-shell nanogels containing different mixtures of LaF<sub>3</sub>:Eu/LaF<sub>3</sub>:Tb nanoparticles. Nanogel solutions at 6.0 mg/mL were diluted by a factor of 100. The excitation wavelength was 393 nm. Emission is due to the Eu ions in the sample. The sample notation is defined in Table 3 of the main text.