

**Emulsion Polymerization Induced Self-Assembly of Thermoresponsive Polymer,
Poly(N-vinylcaprolactam)**

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Electronic Supplementary Information

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1. Synthesis of mCTAs

1. Step: Monomethoxy poly(ethylene glycol) mPEG₁₁₃-OH (20.16 g, 4 mmol) and triethylamine (1.238 g, 12 mmol) were dissolved in 100 ml of anhydrous CH₂Cl₂ in a dry 250 ml three-necked flask placed in an ice bath. A solution of 2-bromopropionyl bromide (1.3 ml, 12 mmol) in 20 ml of anhydrous CH₂Cl₂ was added dropwise to the solution over 2 h. After the addition, the mixture was taken off the ice and stirring was continued for 1 d.

The solution was filtered and 200 ml of CH₂Cl₂ was added. The organic layer was washed with 1 M HCl solution (3 × 80 ml), 1 M NaOH solution (3 × 80 ml), and deionized water (2 × 80 ml) and dried with anhydrous MgSO₄. The solution was concentrated in a rotary evaporator. The polymer was precipitated in 400 ml of cold diethyl ether and dried in vacuum, giving mPEG₁₁₃-Br. Gravimetric yield: 19.4 g (96 %). Product analyzed with ¹H-NMR in DMSO-d6, 20 mg ml⁻¹.

The same procedure was used for the preparation of mPEG₄₂-Br. Gravimetric yield: 89%.

2. Step: mPEG₁₁₃-Br (5.00 g, 1 mmol) and potassium ethyl xanthogenate (0.480 g, 3 mmol) were mixed with 100 ml of anhydrous CH₂Cl₂, reaction time was 30 min. Solids were filtered off and 50 ml of CH₂Cl₂ were added.

The solution was washed with saturated NaHCO₃ solution (3 × 70 ml) and deionized water (1 × 70 ml). The organic phase was dried with anhydrous MgSO₄ and concentrated to 20 ml at 30 °C using a rotary evaporator. The polymer was precipitated in 400 ml of cold diethyl ether. The product was dried under atmosphere overnight. mPEG₁₁₃-X was obtained. Gravimetric yield: 4.64 g (93%). Product analyzed via ¹H-NMR in DMSO-d6, 20 mg ml⁻¹.

In the preparation of mPEG₄₂-X from mPEG₄₂-Br, only a 10 min reaction time was used. Longer reaction times seemed to promote difficulties in removing unreacted xanthate from the products, as indicated by impurities in ¹H-NMR spectra. Gravimetric yield: 90%.

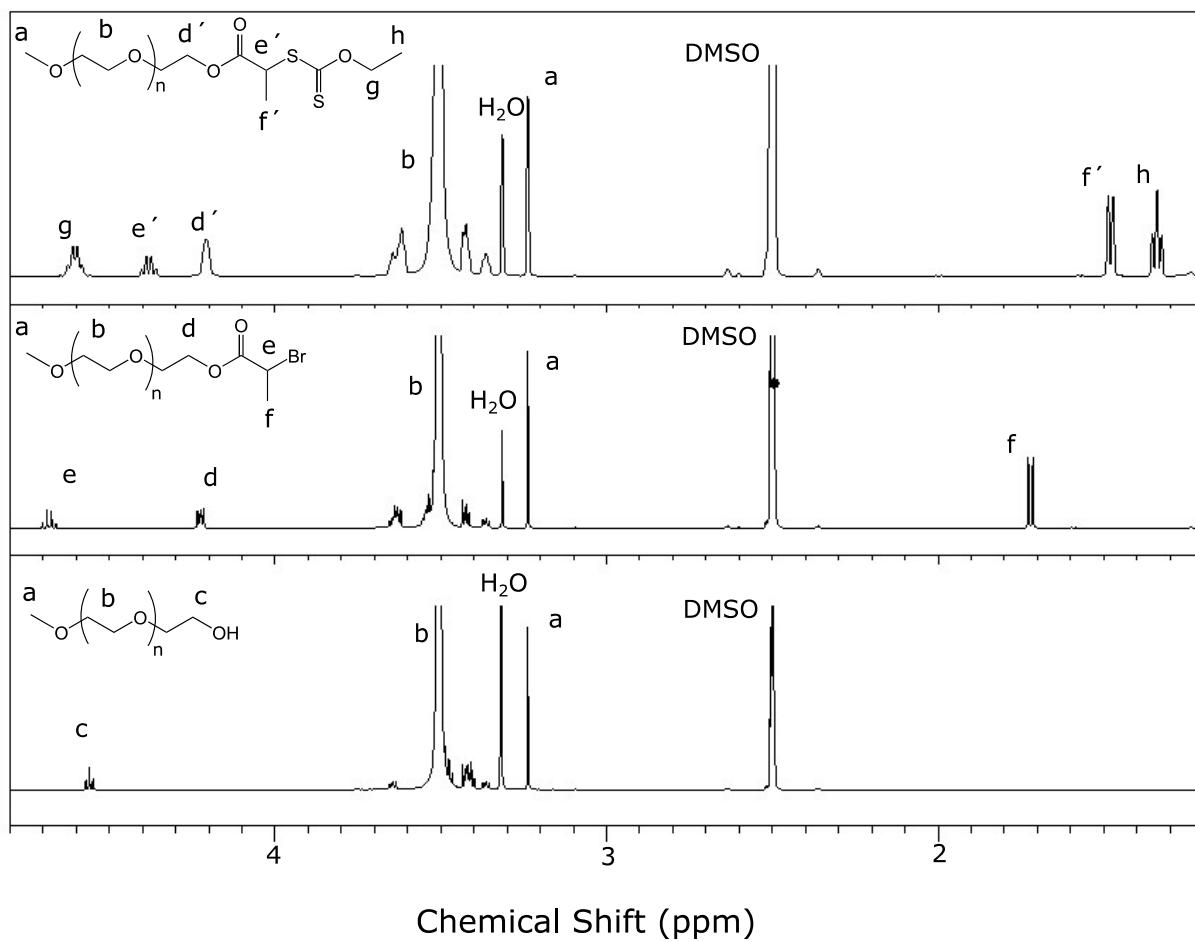


Figure S1. ¹H-NMR spectra

¹H-NMR (mPEG2000-OH, 500 MHz, DMSO, δ): 4.56 (t, 1H, OH), 3.51 CH₂ (m, 4H per repeating unit of PEG = 181 H), 3.24 (s, CH₃O),

¹H-NMR (mPEG2000-Br, 500 MHz, DMSO, δ): 1.72 (d, 3H, CH₃), 3.24 (s, 3H, CH₃O), 3.51 CH₂ (m, 4 per repeating unit of PEG), 4.2 (m, 2H, CH₂OCO), 4.69 (q, 1H, CHBr)

¹H-NMR (mPEG2000-X, 500 MHz, DMSO, δ): 1.34 (t, 3H, CH₃CH₂O), 1.48 (d, 3H, CH₃), 3.24 (s, CH₃O), 3.51 CH₂ (m, 4 per repeating unit of PEG), 4.21 (S, 2H, CH₂OCO), 4.39 (q, 1H, CHS), 4.62 (q, 2H CH₂CH₃)

¹H-NMR (mPEG5000-OH, 500 MHz, DMSO, δ): 4.56 (t, 1H, OH), 3.51 CH₂ (m, 4 per repeating unit of PEG = 452 H), 3.24 (s, 3H CH₃O),

¹H-NMR (mPEG5000-Br, 500 MHz, DMSO, δ): 1.72 (d, 3H, CH₃), 3.24 (s, 3H CH₃O), 3.51 CH₂(m, 4H per repeating unit of PEG), 4.2 (m, 2H, CH₂OCO), 4.69 (q, 1H, CHBr)

¹H-NMR (mPEG5000-X, 500 MHz, DMSO, δ): 1.34 (t, 3 H, CH₃CH₂O), 1.48 (d, 3 H, CH₃), 3.24 (s, 3H CH₃O), 3.51 CH₂(m, 4 per repeating unit of PEG), 4.21 (S, 2H, CH₂OCO), 4.39 (q, 1H, CHS), 4.62 (q, 2H CH₂CH₃)

2. ¹H-NMR of a typical product and starting materials

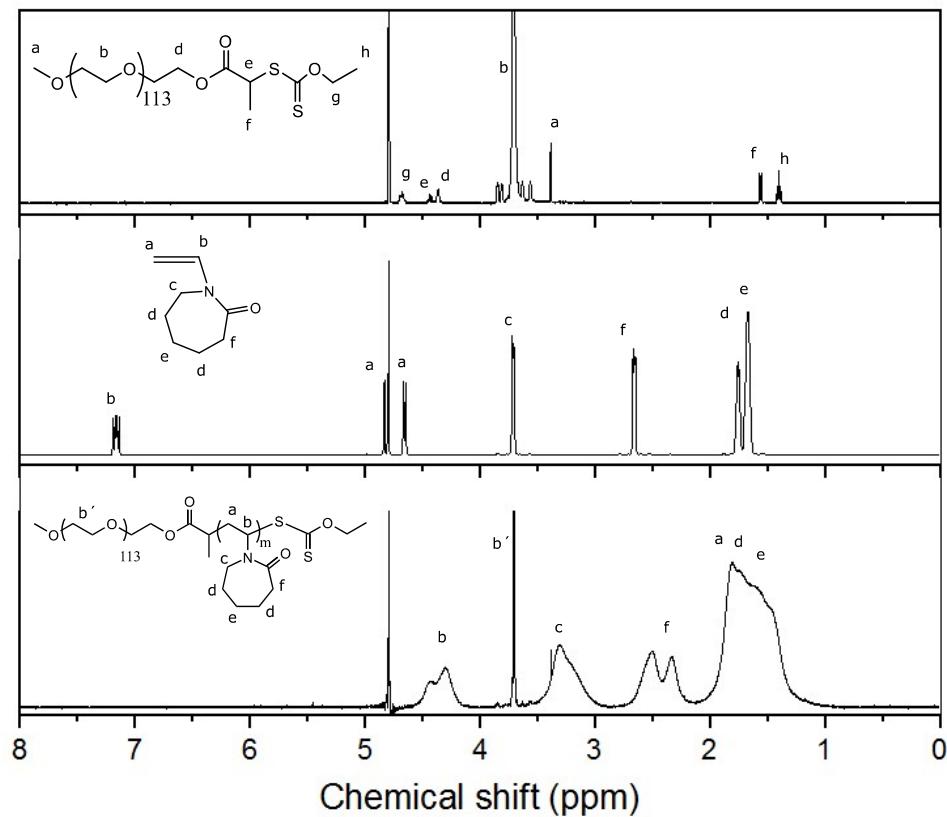


Figure S2. ¹H-NMR spectra of PEG₁₁₃-X (top), NVCL (middle), PEG-b-PNVCL (bottom) with peak assignations

3. Conversion analysis of a typical product via $^1\text{H-NMR}$

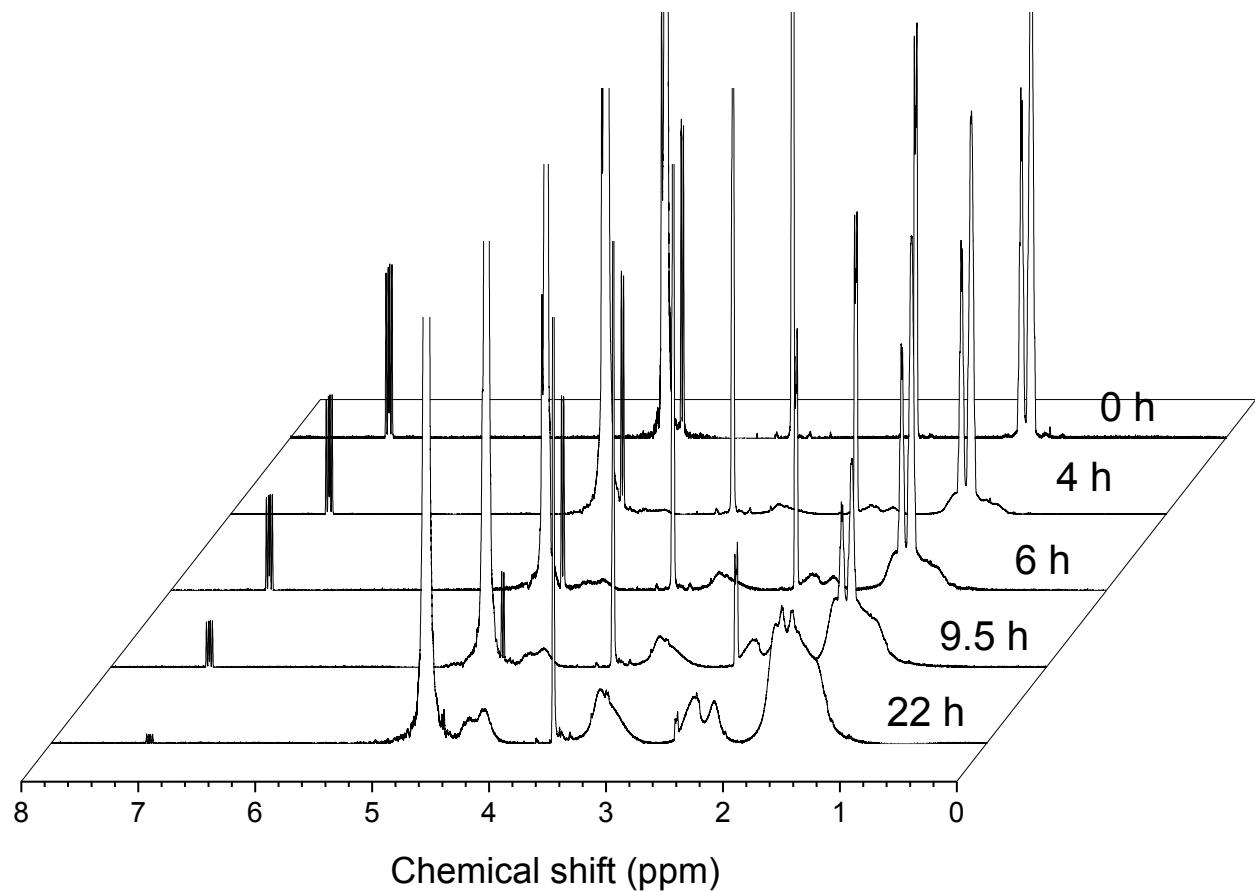


Figure S3. $^1\text{H-NMR}$ spectra of conversion samples taken at different time intervals from reaction mixture (D_2O)

Conversion was calculated from the integrals of $^1\text{H-NMR}$ spectra presented in figure according to equation 1. In short integral coming from a proton of NVCL (at 7 ppm) was compared to a peak assigned to 2 protons from either NVCL or PNVCL repeating unit (2.8 to 2 ppm).

$$Conversion = 1 - \frac{\int_{2ppm}^{2.8ppm} \delta(x)dx}{\int_{6.8ppm}^{7.2ppm} \delta(x)dx}$$

[S1]

4. Kinetics of polymerizations with varying mCTA and initiator concentration

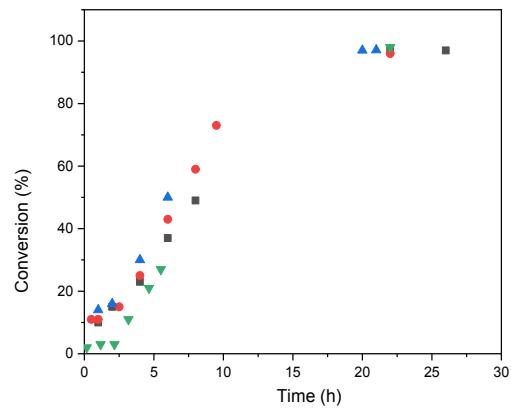


Figure S4. Conversion versus time for polymerizations with varying mCTA and initiator concentrations; DP = ▲ 194, ● 340, ■ 485, or ▼ 980

5. M_n of the high molecular weight PNVCL via $^1\text{H-NMR}$

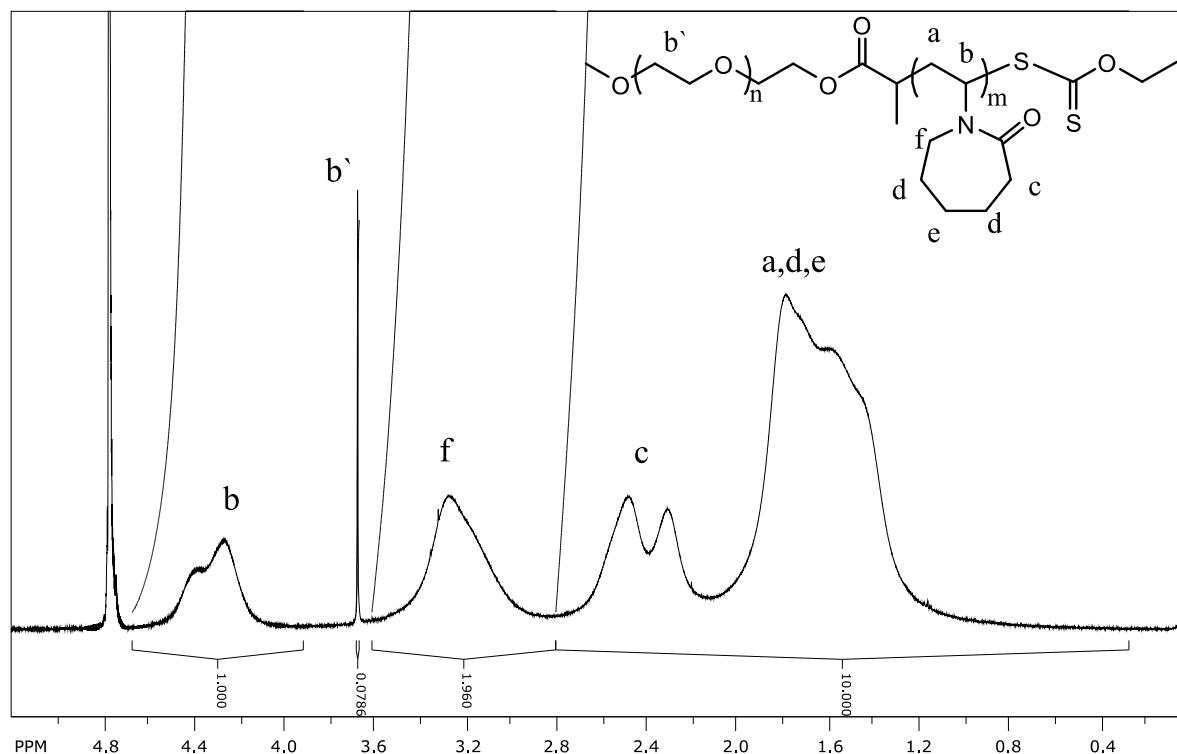


Figure S5. $^1\text{H-NMR}$ spectra of high molecular weight PNVCL in D_2O

$$M_n = \frac{n \text{ of repeating units of VCL}}{n \text{ of PEG chains}} * M(\text{NVCL}) + M_n(\text{mCTA}) = \frac{\int b \, dx}{\int b' \, dx / (113 * 4)} * 139.19 \text{ g/mol} + 5000 \text{ g/mol}$$

[S2]

$$M_n = \frac{1}{0.078 / (113 * 4)} * 139.19 \text{ g/mol} + 5000 \text{ g/mol} = 810\,000 \text{ g/mol}$$

6. SEC Chromatogram of the high molecular weight PNVCL

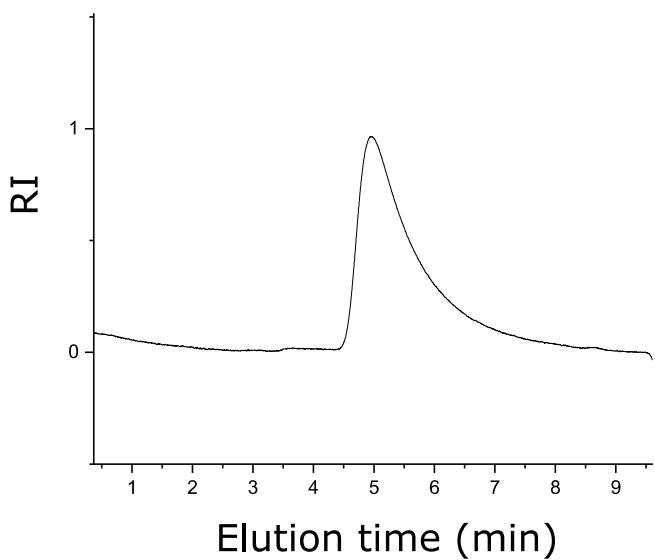


Figure S6. SEC chromatogram of the high molecular weight PNVCL in THF

7. M_w of the high molecular weight PNVCL via SLS

Refractive index increment (dn/dc) was determined for the high molecular weight polymer in THF with Wyatt Optilab rEX differential refractometer at 25 °C 633 nm. The obtained dn/dc value was 0.137.

The M_w measurements were performed using a setup with Brookhaven Instruments BI-200SM goniometer, a BIC-TurboCorr digital pseudo-cross-correlator, and a BI-CrossCorr detector and a red 637 nm BI-mini L140 operated with 50 mW power was used as light source and. Sample cell was connected to a Lauda RC 6 CP thermostat and temperature was set to 25 °C. Goniometer alignment was checked before measurements and calibration was done at 90° with toluene. Zimm-plot software was used for M_w determination.

$$M_w = 1\,270\,000 \pm 49\,000 \text{ g/mol.}$$

$$\text{Second viral coefficient } (A_2) = 2.43 \times 10^{-4} \text{ cm}^3 \text{ mol/g}^2$$

$$R_g = 59.8 \text{ nm}$$

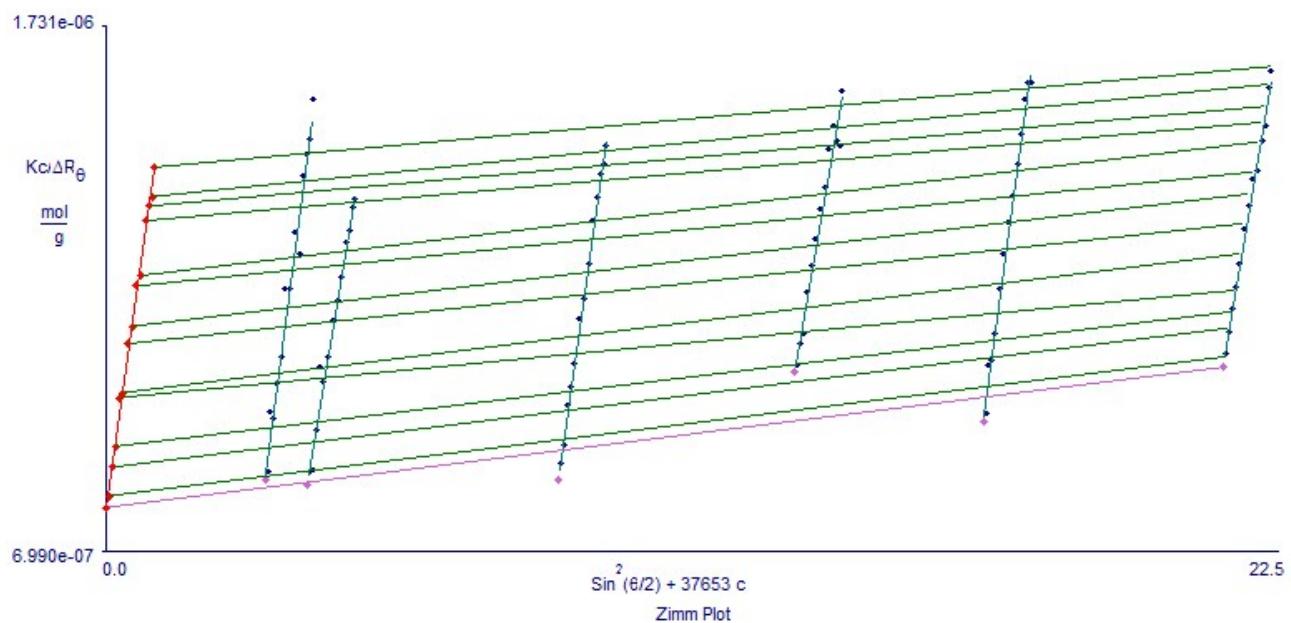


Figure S7. Zimm plot for high M_n PVCL

8. LS data of polymerizations with varied total concentration

$$[M_0] / [mCTA] / [I] = 500 / 1 / 0.3$$

Table S1. Effect of polymerization concentration, with LS data

[NVCL] ₀ (g/ml)	Conv. (%)	Mn _{theory} (g/mol)	Mn _{SEC} (g/mol)	D (M _n /M _w)	D _h * (nm)	R _g / R _h *
0.1	97	72 500	72 300	1.5	225	0.76
0.2	98	73 200	71 400	1.4	220	0.74
0.3	98	73 200	72 100	1.3	245	0.78

*measured at 50 °C from diluted particle dispersion before cooling

9. DLS data of polymerizations with varied initiator concentration

Table S2. Synthesis of polymers with different initiator concentrations, with LS data

$$C_0(\text{NVCL}) = 0.1 \text{ g / ml} \text{ i.e } [M]_0 = 0.718 \text{ mol / l}$$

[M] ₀ :[CTA]:[I]	Conv. (%)	Mn _{theory} (g/mol)	Mn _{SEC} (g/mol)	D (M _n /M _w)	D _h * (nm)	R _g / R _h *
500/1/0.3	97	72 500	72 300	1.5	220	0.77
500/1/0.6	99	73 900	74 700	1.2	225	0.80
500/1/0.9	100	74 600	75 700	1.2	210	0.82

*measured at 50 °C from particle diluted dispersion before cooling

10. Cryo-TEM images of the high M_n polymer particles

This cryo-EM sample was imaged with FEI Tecnai F20 microscope and micrographs were recorded with Gatan US4000 CCD camera.

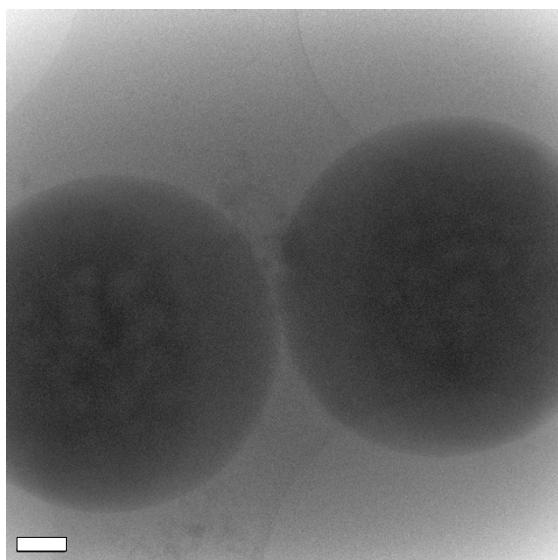


Figure S8. Cryo-TEM image of high M_n polymer particle, scale bar is 200 nm wide.

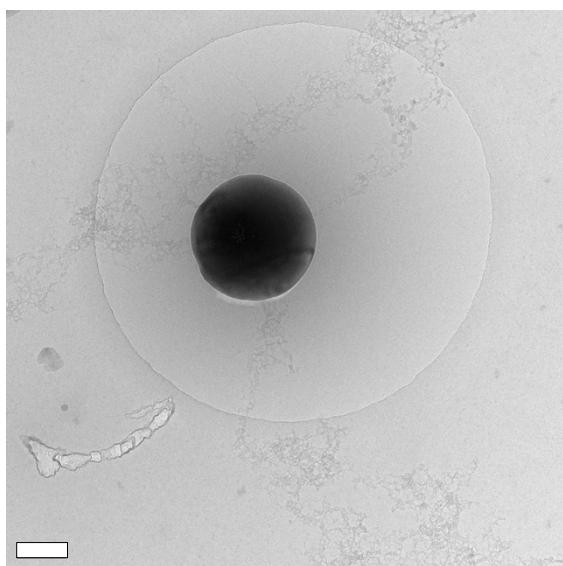


Figure S9. Another cryo-TEM image of high M_n polymer particle, scale bar is 200 nm wide.

11. Solubility of NVCL to H_2O and to TRIS buffer (100 mM, pH = 7.4)

Solubility of NVCL to TRIS buffer (100 mM, pH = 7.4) at 22 °C and at 50 °C were tested. At 22 °C, 5 ml of TRIS was mixed with 500 mg of NVCL at room temperature for 2 days to get saturated solution. Insoluble material was separated via centrifugation (2h, 10 000 rcf). 0.1 ml of supernatant was diluted with 1 ml D₂O. The amount of dissolved NVCL was determined via ¹H-NMR by comparing integral from TRIS protons with integral from NVCL (1 of the ¹H-NMR spectra presented as figure S10). Experiment was performed in triplicate.

Solubility of NVCL to 100mM TRIS at 22 °C is 35 ± 2 g/L.

Solubility of NVCL to TRIS buffer at 50 °C was tested by mixing 5 ml of TRIS with 500 mg of NVCL for 4 h to get saturated solution. At 50 °C, the monomer is liquid and the mixing time was deemed sufficient via number of test with different mixing times. Supernatant was separated via centrifugation (30 min, 3773 rcf, at 50 °C). 0.1 ml of supernatant was diluted with 1 ml D₂O. The amount of dissolved NVCL was determined by comparing integral from TRIS protons with integral from NVCL. Experiment was performed in triplicate.

Solubility of NVCL to 100mM TRIS at 50 °C is 36 ± 2 g/L.

Solubility of NVCL to H₂O was tested at 22 °C. Test was same as with TRIS at 22 °C. Only difference was that after centrifugation supernatant was mixed in 1 to 1 ration with 100 mM TRIS. 0.1 ml of the mixture was diluted with 1 ml D₂O. The amount of dissolved NVCL was determined via ¹H-NMR by comparing integral from TRIS protons with integral from NVCL. Experiment was done in triplicate.

Solubility of NVCL to H₂O at 22 °C is 15 ± 2 g/L.

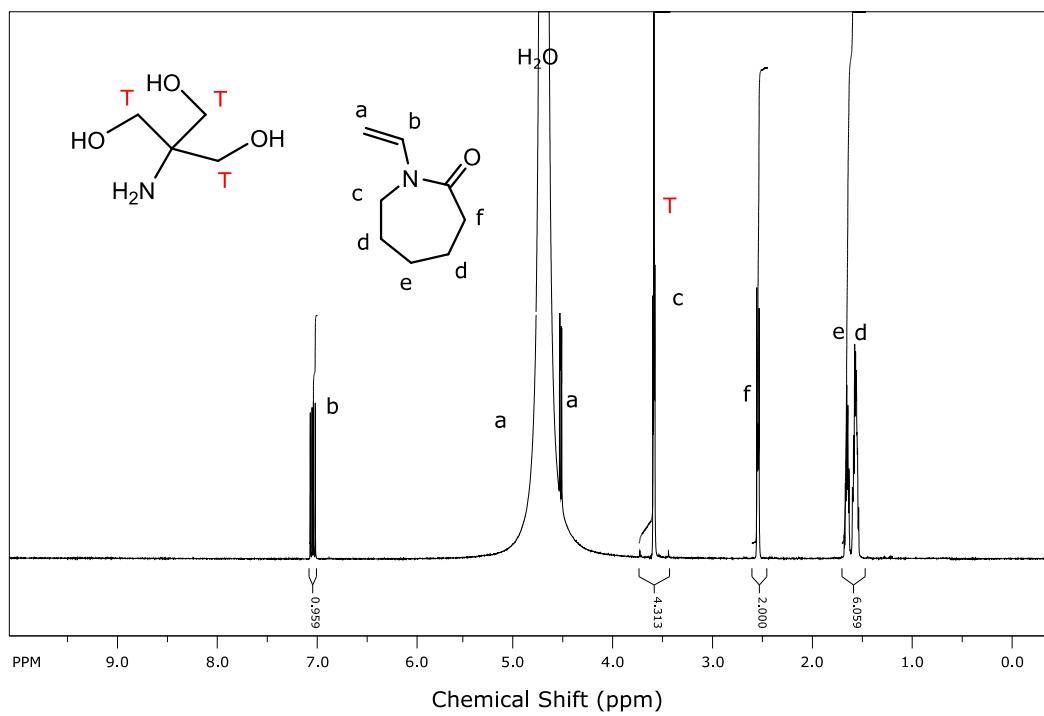


Figure S10. ^1H -NMR spectrum from solubility test