

Supplementary Movie 1. Swelling Behavior of Conventional Chemically Crosslinked PNIPAM Systems Under Varied Temperatures and Saline Environments. Dry PNIPAM films were fabricated via covalently cross-linked free radical polymerization. Subsequently, these films were subjected to swelling treatments in three distinct media: sodium thiocyanate (NaSCN) aqueous solution, deionized water, and sodium sulfate (Na₂SO₄) aqueous solution. The swelling processes were conducted at two temperatures: 40°C and 60°C.

Supplementary Movie 2. Swelling Behavior of Physically Crosslinked PNIPAM Systems Under Varied Temperatures and Saline Environments. Initially, the poly(NIPAM-co-PrMA) (abbreviated as N_xPM_y) dry film exhibited full transparency, and it was sequentially transferred to water baths maintained at 7°C, 28°C, and 65°C (redundant transfer description in the original text is streamlined here). At 7°C, the film retained its transparency with no visible turbidity change; at 65°C, obvious turbidity alterations were observed in the film; and at 28°C, distinct turbidity changes occurred in the N₅₈PM₄₂ and N₄₄PM₅₆ copolymer films, while the N₂₇PM₇₃ film remained transparent.

Supplementary Movie 3. SDTP-Gel Preparation Steps (Weighing, Dissolving, Casting, Demolding) and Dry Film Properties Post-Swelling. This movie presents the preparation procedure of SDTP-gel, covering sequential operational steps: weighing polyvinylpyrrolidone (PVP) blocks, measuring N,N-dimethylformamide (DMF) solution, dissolving the components for film casting, demolding the formed gel, and exhibiting the properties of the dry film following its swelling process.

Supplementary Movie 4. Reversible Transparency Over 500 Heating Cycles (28°C–36°C). This movie demonstrates the transparency evolution of SDTP-gel over repeated heating cycles (between 28°C and 36°C) following equilibration at 30°C. A total of 500 cycles were conducted, with representative segments featured for cycles 1–20, 180–200, 301–320, and 480–500. The gel displays reversible transparency transitions throughout these cycles, highlighting its outstanding durability and structural stability.

Supplementary Movie 5. Long-Term Stability of The Opaque State. This movie shows the performance of an SDTP-gel after being kept above its phase transition temperature for an extended period. The opaque state remains stable for at least 36 hours with no visible decay or coarsening, confirming the long-term stability of the phase-separated structure.

Supplementary Movie 6. SDTP-Gels (Varied Water Contents): Depth-Varied Confocal Imaging of Phase-Separated Structures (Nile Red, 10 μm Scale). This movie presents the phase-separated structures of SDTP-gels with varying water contents via confocal imaging — which includes scans at different depths to capture the three-dimensional structural characteristics of the gels. The polymer components in the gels are stained with Nile red to enhance visualization of the phase-separated regions, and the scale bar for all imaging results in this video is set to 10 μm.

Supplementary Movie 7. SDTP-Gel Low-Temperature Adaptability: 5°C Swelling (Transparent) → -3°C Re-Swelling → Cloudy at 5°C. This movie illustrates the low-temperature adaptive properties of SDTP-gel. The SDTP-gel was first subjected to swelling in a 4 M sodium thiocyanate (NaSCN) aqueous solution at 5°C, with the process maintained for 2 days to achieve swelling equilibrium — during this period, the gel remained in a transparent state at 5°C. Subsequently, the gel was re-swollen at -3°C for 1.5 hours; after this low-temperature treatment, the gel exhibited a cloudy (turbid) state when returned to 5°C, thereby demonstrating its responsive adaptive behavior under low-temperature conditions.

Supplementary Movie 8. Low-Temperature Indicator + MATLAB Analysis: Estimate Storage Environment's Low-Temperature Exposure (Temperature/Duration). This movie illustrates the method for estimating the low-temperature exposure duration of a storage environment using a low-temperature indicator. The indicator starts as transparent at 5°C; after exposure to an unknown low-temperature environment, it is returned to 5°C, then photographed, cropped, and uploaded (renamed) to a computer's Real-time Analysis folder. White level analysis is conducted via MATLAB, and the pseudo-color map's red dashed lines are used to deduce the storage environment's likely low temperatures and exposure duration.

Supplementary Movie 9. Poly(AA-co-EOEOEA) exhibits tunable phase transition temperatures depending on the swelling temperature. The turbidity transition is rapid and occurs uniformly across the entire sample, demonstrating a reversible transparent-to-opaque change that records thermal history.