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Direct Removal of Silicon-Containing Species from Uranium-Bearing ISL Process Liquor

*Analytical Characterization, Pre-IX Desilication Pathways and Stage-Gated Pilot
Evaluation for Kazakhstan*

EESEF — TECHNICAL REPORT SERIES

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Abstract

This technical report examines the direct removal of silicon-containing species from uranium-bearing in-situ leach (ISL) process liquor before uranium ion exchange (IX), addressing a technical challenge relevant to Kazakhstan uranium ISL processing. The principal uncertainty is the form and distribution of silicon in the process liquor; therefore, the report does not assume that the problematic fraction is simply particulate silica, dissolved silicate, or a single molecular species. Instead, it proposes an operational characterization framework combining total and filtered silicon measurements, molybdate-reactive silica, solids characterization, and full process-matrix chemistry. The assessment reviews direct pre-IX treatment pathways including phase conversion and precipitation, magnesium-assisted removal, selective inorganic sorbents, and silicon-carbide ceramic membrane filtration for particulate, colloidal, or deliberately precipitated silicon-bearing material. Supplier-provided Chinese industrial experience is treated as a technology-transfer reference rather than proof of performance in Kazakhstan uranium liquor. A small-scale experimental treatment unit was delivered to a university in Almaty in September 2026, but testing had not begun as of the publication date and no Kazakhstan process-liquor performance data are available. Accordingly, no treatment-performance claim is made. The recommended program is stage-gated and requires independent analytical verification, uranium mass balance, solids characterization, downstream IX testing, and assessment of reagent, waste, water, corrosion, and operating impacts before scale-up. From an ESG perspective, the work focuses on measurable resource efficiency, chemical and waste reduction, protection of uranium recovery, transparent evidence classification, and responsible process-water management. EEESEF's role is non-commercial and vendor-neutral: to support environmental science, university-industry technical cooperation, and independent evaluation of candidate solutions.

Document Status and Qualification

This edition focuses the report on direct removal of silicon-containing species from uranium-bearing process solution before uranium ion exchange.

Supplier information and photographs are identified as supplier-provided and unverified for Kazakhstan uranium PLS. Chinese manufacturer names and individual names are intentionally omitted.

All numbered citations in the body correspond to the numbered reference list in this document.

This report is an independent technical report and pilot-evaluation framework, not detailed engineering, regulatory approval, or a guarantee of process performance.

Project Logic: Direct Removal of Silicon-Containing Species Before Uranium IX

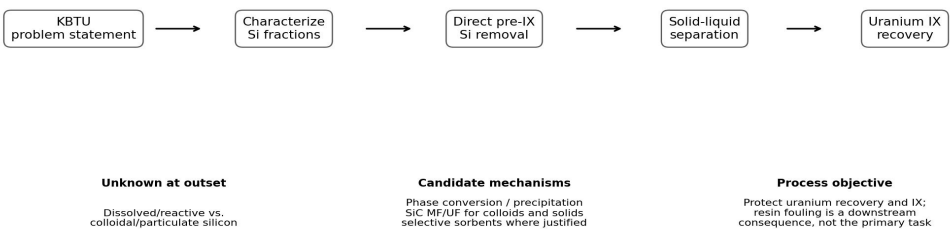


Figure 1. Revised project logic: upstream solution-phase silicon removal is the primary task; resin fouling is the downstream consequence.

Executive Summary

Kazakhstan produced 25,839 tonnes of uranium (tU) in 2025, approximately 40% of global mine production, and its uranium industry relies predominantly on in-situ leach (ISL) recovery [1,2]. In these circuits, uranium-bearing pregnant leach solution (PLS) is commonly treated by ion exchange (IX). High-silica uranium liquors are a documented operational challenge because silica accumulation on or within anion-exchange resin can impair uranium loading and elution kinetics [6,7].

The technical question addressed by this report is more specific than resin fouling. The working hypothesis is that an operationally significant fraction of the problematic silicon may be present in dissolved, colloidal or otherwise non-readily-filterable form in the process solution, while its exact nature and distribution have not yet been established. Characterization of the silicon-containing species is therefore a mandatory first step before selecting a treatment. This hypothesis is treated as a question to be tested, not as verified analytical data.

Accordingly, the primary objective of this report is direct removal of silicon-containing species from the uranium-bearing process solution before contact with the uranium IX resin. Resin fouling and NaOH regeneration are retained as downstream context and as evidence of why upstream control may be valuable; they are not the principal treatment objective.

A Chinese technology supplier has provided EESEF with photographs and a description of an industrial process package used to clarify a silica- and pigment-containing hydrochloric-acid byproduct stream by converting/removing the problematic material before reuse. The case is technically relevant as an acidic-liquor desilication precedent, but it is not uranium service, uses a different acid/matrix, and has not been independently verified by EESEF [13]. It therefore constitutes a candidate technology-transfer case, not proof of applicability to Kazakhstan ISL PLS.

The recommended program begins with operational fractionation: unfiltered and 0.45 µm-filtered total silicon by ICP-OES/ICP-MS; laboratory molybdate-reactive silica by ASTM D859 or a validated equivalent; TSS/turbidity/particle-size characterization; and a matrix panel including uranium, sulfate, Fe, Al, Ca, Mg and other relevant ions [3,5]. ASTM D7126 is reserved for online soluble-silica monitoring because its scope explicitly excludes laboratory/grab-sample measurement [4].

If a material dissolved/molybdate-reactive silicon fraction is confirmed, candidate direct-removal mechanisms should be screened on actual PLS. These may include phase conversion/precipitation, magnesium-assisted silica removal, and selective inorganic sorbents [8,9]. Every test must include a uranium mass balance. A process that removes silicon but causes material uranium loss, excessive sludge, unacceptable pH adjustment or downstream chemistry problems is not a viable solution.

From an ESG perspective, the strongest direct benefits are resource efficiency, lower chemical and resin-management burden, reduced waste generation and improved process reliability. Kazakhstan's wider water-security context makes disciplined water and chemical management important [10]. Groundwater restoration is a separate hydrogeological issue and is not presented here as a direct consequence of surface-plant silica fouling [11]. EESEF's role is non-commercial: to define the problem, distinguish evidence from supplier claims, establish a rigorous test program, and support independent evaluation without endorsing any manufacturer or technology.

1. Purpose, Origin and Scope of the Assessment

This technical report addresses an operational challenge relevant to uranium in-situ leach (ISL) processing in Kazakhstan: the presence of silicon-containing species in uranium-bearing process liquor and the need to determine whether these species can be removed before uranium ion exchange (IX). Silica-related deterioration of ion-exchange performance is documented in uranium-processing literature, but the form, concentration and operational significance of silicon in any specific process liquor must be established through site-specific analytical characterization. For the purposes of this report, the working hypothesis is that at least part of the operationally significant silicon burden may occur in dissolved, colloidal or otherwise non-readily-filterable form. This hypothesis has not yet been confirmed by a site-specific analytical dataset and is therefore treated as a question to be tested rather than an established process condition.

EESEF subsequently sought technical information from a Chinese technology supplier. Initial supplier material focused on silica-related deterioration of uranium-adsorption resin and NaOH regeneration. EESEF clarified that the primary requirement is upstream removal of silicon-containing compounds from the solution itself. The supplier then provided an industrial acidic-liquor reference case and equipment images for direct desilication/clarification [13].

The report therefore has four objectives: (1) define the silicon problem without assuming its species; (2) establish a defensible analytical characterization program; (3) compare direct pre-IX removal pathways, including the Chinese acidic-liquor reference case, on a vendor-neutral basis; and (4) define a stage-gated bench/pilot program that protects uranium recovery and supports environmental, operational and ESG decision-making.

This is an independent technical report. It is not detailed engineering, a process guarantee, a regulatory approval, or an endorsement of any supplier.

2. Evidence Hierarchy and Terminology

Four evidence classes are used throughout: A - established external evidence from standards, peer-reviewed literature or authoritative institutions; B - site-specific operator or independent-laboratory data with documented QA/QC; C - supplier/partner-reported information not independently verified; and D - hypotheses or proposed pilot criteria requiring validation.

The phrase 'ionic silicon' is not used as a confirmed description of acidic PLS. ASTM D859 notes that silica in water can occur in suspended, colloidal or dissolved forms and, in solution, as silicic acid or silicate ion depending on pH [3]. For this project the preferred terms are 'dissolved silicon', 'molybdate-reactive silica', 'non-molybdate-reactive operational fraction', and 'particulate-associated silicon', unless site-specific analytical work supports more detailed speciation.

Similarly, the supplier/partner suggestion that the material is likely SiO₂ is treated as a hypothesis. Reporting analytical results as Si or SiO₂ equivalents does not by itself establish the molecular or particulate form present.

3. Kazakhstan ISL Context and Why Upstream Silicon Control Matters

Kazakhstan has been the world's leading uranium producer since 2009 and produced about 25,839 tU in 2025 [1]. ISL dominates production. In acid ISL, leaching solution is circulated through permeable uranium-bearing formations, PLS is recovered to surface, and uranium is commonly captured by IX [2].

Independent uranium-processing literature confirms that silica fouling is a real IX problem in acidic sulfate uranium liquors. US Patent 7,655,199 describes high-silica uranium leachates and states that silica fouling affects both loading and elution kinetics [6]. Published resin-comparison work likewise describes silica fouling in sulfuric-acid uranium liquors and poorer metallurgical performance as silica accumulates [7].

This evidence establishes the downstream consequence but does not establish the best upstream treatment. The purpose of direct pre-IX silicon removal is therefore to reduce the silicon burden presented to the uranium-recovery resin while preserving uranium and the solution chemistry required for recovery.

4. Analytical Characterization Before Technology Selection

The analytical objective is operational fractionation rather than complete molecular speciation. Complete silica speciation is difficult and is not provided by a single routine colorimetric test. The minimum program should distinguish total, operationally dissolved, molybdate-reactive and particulate-associated fractions, together with the process matrix that controls treatment behavior.

Total and dissolved silicon: determine Si by ICP-OES or ICP-MS on paired unfiltered and 0.45 μm -filtered aliquots using a method validated for acidic, sulfate-rich uranium liquor. The difference can be used as an operational estimate of particulate-associated silicon, with uncertainty and filtration artifacts recognized.

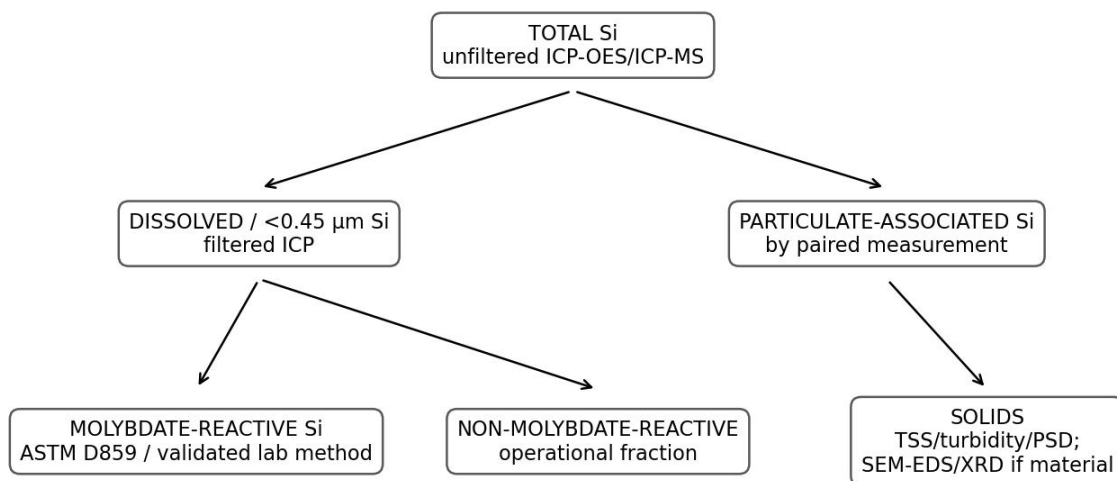
Molybdate-reactive silica: ASTM D859 is appropriate for laboratory/grab samples, subject to matrix validation. ASTM defines the measurand operationally and notes that it includes dissolved simple silicates, monomeric silica/silicic acid and an undetermined fraction of polymeric silica [3]. ASTM D7126 is an online colorimetric method and explicitly states that it does not cover laboratory or grab samples; it refers users to D859 [4].

Solids: TSS, turbidity and PSD characterize the burden and size of suspended material but do not identify its chemistry. Where solids are material, SEM-EDS and/or XRD should be used to determine whether silicon-bearing phases, clay, iron/aluminium precipitates, calcium salts or other phases dominate.

Matrix chemistry: record pH, temperature, conductivity/TDS, sulfate, uranium, Fe, Al, Ca, Mg, Na and relevant competing ions such as chloride, fluoride, vanadium and molybdenum where applicable. The need is practical: precipitation or adsorption methods can alter uranium chemistry or create secondary solids.

QA/QC should include duplicates, blanks, appropriate calibration standards, matrix spikes or standard additions where interference is significant, documented filtration timing and preservation, and consistent reporting units. Results must state whether silicon is reported as mg/L Si or mg/L SiO_2 .

Analytical Framework Required Before Technology Selection



Operational fractionation - not complete molecular speciation.

Figure 2. Operational fractionation framework. ASTM D859 is used for laboratory/grab-sample molybdate-reactive silica; D7126 is an online method [3,4].

5. Sampling Strategy

Minimum sampling points are: S1 native/background groundwater before process reagents; S2 recovered PLS after ore-zone contact; S3 immediately before any pretreatment/IX step; and S4 after the relevant pretreatment or IX step. For a desilication pilot, additional samples are required from treated liquor, separated solids/sludge and any recycle or regenerant stream.

At least three temporally separated campaigns are recommended before defining a design basis unless existing operator data demonstrate lower variability. Wellfield stage, acidification history, residence time, temperature and operating cycle should be recorded where available.

The output should be a silicon and uranium mass balance, silicon fraction distribution, matrix chemistry, uncertainty range and baseline IX performance dataset.

6. Direct Pre-IX Silicon Removal: Technology Landscape

If the problematic fraction is mainly particulate/colloidal, clarification, media filtration or MF/UF may be sufficient. If it is mainly dissolved/molybdate-reactive, MF/UF alone should not be assumed to remove it; a phase-conversion, precipitation, adsorption or other separation mechanism is required.

Magnesium-assisted precipitation/softening is supported by peer-reviewed industrial-water research. Latour et al. reported high silica removal at elevated pH after magnesium addition in a high-silica, low-hardness industrial effluent [8]. The study supports the mechanism but not direct transfer of its reagent doses to uranium PLS.

Mixed hydrotalcite/activated-alumina oxides have demonstrated strong dissolved-silica uptake in industrial cooling water even in the presence of competing anions including sulfate [9]. This makes the mechanism worthy of bench screening, but its capacity, uranium interaction, regeneration behavior and stability in strongly acidic uranium PLS remain unverified.

Nanofiltration or reverse osmosis can reject dissolved silica in some water-treatment applications, but their use on uranium PLS would require a separate membrane compatibility, uranium-retention, concentrate-management and fouling assessment. They are not assumed to be the preferred solution here.

NaOH cleaning of already-fouled uranium resin remains a corrective maintenance option supported by uranium-resin literature and supplier experience [6,7,13]. It is not a substitute for the upstream direct-removal objective.

7. Chinese Acidic-Liquor Reference Case - Relevance and Limits

Following EESEF's definition of the project objective as direct removal of silicon-containing species from the solution before uranium IX, a Chinese technology supplier described an industrial process package used on a hydrochloric-acid byproduct stream containing substantial silica-bearing material and pigments. According to the supplier, the untreated acid is turbid and unsuitable for reuse, while the treatment converts/removes the problematic material and produces a clear, colorless stream suitable for reuse in other chemical operations [13].

The photographs supplied to EESEF show a packaged skid with vertical process vessels, pumps, automated valves and a control cabinet, consistent with an industrial liquid-treatment system. A second image is a supplier engineering rendering with numbered components. The photographs demonstrate equipment existence; they do not independently establish process chemistry, removal efficiency, capacity or suitability for uranium service.

The reference is relevant because it represents direct treatment of a strongly acidic silica-containing process stream rather than post-fouling resin cleaning. Its transfer gap is nevertheless substantial: the reference stream is hydrochloric-acid based and non-uranium, whereas Kazakhstan ISL PLS is expected to be sulfate-dominated and contains uranium plus site-specific Fe, Al, Ca, Mg and other ions. Before pilot use, EESEF should obtain the supplier's feed/treated chemistry, silicon analytical method, reagent identity/dose, pH profile, residence time, solids production, materials of construction, throughput, mass balance and operating history.

The Chinese reference case is therefore classified as Evidence Class C: a credible candidate for controlled evaluation, but not a proven Kazakhstan solution. No manufacturer name is required for the technical report.



Photo 1. Supplier-provided industrial acidic-liquor treatment skid. Manufacturer identity omitted. Equipment existence is visible; process performance is not independently verified [13].

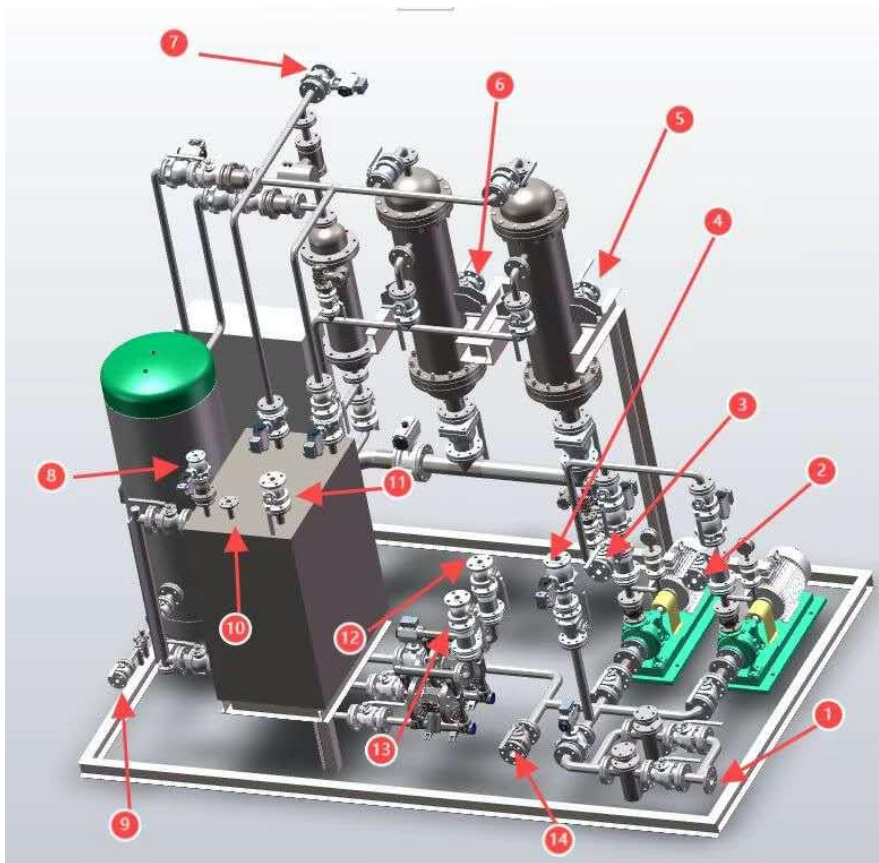


Photo 2. Supplier-provided engineering rendering of the treatment package. Component numbering is supplier-originated; detailed process duty has not been independently verified [13].

7A. Additional Supplier Hypotheses: Scientific Interpretation

The supplier subsequently provided additional statements about the form of silicon in the feed and the proposed removal mechanism. Several statements are useful as testable hypotheses, but the translated terminology is not sufficiently precise to be adopted as established chemistry. EESEF therefore interprets them conservatively and separates what can be retained from what requires correction or verification [13-16].

The supplier distinguishes between “silicon compounds” and “silicate ion” and suggests that removal of the former, rather than the latter, is the key operational objective. This binary description is oversimplified. In acidic aqueous systems, silicon may occur as monomeric silicic acid, polymeric silicic species, colloidal/amorphous hydrated silica and mineral-derived particulate material; the distribution depends on pH, concentration, ionic strength, temperature and reaction history [14,15]. The project should therefore continue to use operational analytical fractions rather than assume only two liquid-phase forms.

The supplier also proposed that slow acidification or local pH excursions through approximately pH 2-5 may promote continuing silicate dissolution and subsequent polymerization/gel formation. Literature supports the broader proposition that silicic acid can polymerize in acidic media and that polymeric silica can be important at around pH 3, but it does not justify the supplier’s exact pH-1.5 operating prescription for Kazakhstan PLS without site-specific data [14,15]. The acidification history and local pH profile should therefore be recorded as process variables during sampling and pilot work.

The statement that “silicate ion has minimal effect on adsorption” is not accepted as a general conclusion. Its relevance depends on the actual silicon species, resin chemistry and liquor matrix, and should be tested rather than assumed. Likewise, visual cloudiness is evidence of suspended/colloidal material but is not a quantitative measure of dissolved silicon.

7B. Small-Scale Experimental Treatment Unit: Delivery and Planned Evaluation

The Chinese technology supplier developed a small-scale experimental treatment unit for evaluation of the silicon-removal approach. The unit was delivered to a university in Almaty, Kazakhstan, in September 2026. As of October 25, 2026, experimental testing has not begun; initial testing is tentatively anticipated in early November 2026, subject to the university’s schedule and test readiness. The unit is intended to reproduce the relevant treatment sequence at reduced scale and provide a controlled platform for testing representative uranium-bearing process liquor before any consideration of larger-scale implementation [13].

Delivery of the unit is not evidence of demonstrated treatment performance. It remains an experimental process-development platform intended to enable controlled evaluation of the treatment mechanism, operating conditions and solid-liquid separation behaviour, including whether silicon removal can be achieved without unacceptable uranium loss or adverse changes to process-liquor chemistry. No Kazakhstan uranium process-liquor performance results are available at the date of publication.

Experimental evaluation should compare untreated feed with treated liquor and establish silicon-fraction removal, uranium mass balance, major-ion chemistry, solids generation, hydraulic/filtration performance and downstream IX behaviour. Treatment performance should be independently characterized, with results documented separately from this technical report.



Photo 3. Supplier-provided photograph of the small-scale experimental treatment unit delivered to a university in Almaty in September 2026. Testing had not begun as of October 25, 2026; treatment performance remains unverified [13].

7C. Silicon-Carbide Ceramic Membrane as a Candidate Pretreatment

The supplier's Chinese-language presentation describes silicon-carbide (SiC) ceramic membrane technology and shows industrial applications in high-quality wastewater, mine drainage and high-salinity water treatment, together with pilot equipment and engineering references. The presentation is supplier marketing/technical material rather than independent evidence and is therefore classified as Evidence Class C. Its contents support consideration of SiC membrane filtration as a robust physical-separation candidate, but do not demonstrate selective removal of truly dissolved silicon species from uranium PLS.

For the present uranium application, the correct interpretation is:

- SiC microfiltration/ultrafiltration can plausibly remove suspended solids, colloidal silica and nanoscale particulate material when those particles are larger than the effective membrane cut-off.
- A physical porous membrane should not be assumed to remove monomeric silicic acid or small dissolved silicate species merely because the membrane material itself is SiC.
- If a chemical step first converts dissolved/reactive silicon into colloidal or precipitated solids, a chemically resistant ceramic membrane could become the downstream solid-liquid separation step.
- Uranium retention or passage cannot be assumed. Dissolved uranium species may pass a MF/UF membrane, but adsorption, coprecipitation, entrainment and membrane/solid interactions must be measured by a complete uranium mass balance.
- Membrane pore size, permeability, transmembrane pressure, cross-flow velocity, temperature, cleaning protocol, flux decline and solids loading are required before engineering evaluation.

The supplier also states that its system can tolerate sulfuric acid and hydrofluoric acid. High-purity sintered/recrystallized SiC is well known for broad acid resistance, including sulfuric acid; however, HF compatibility is material- and manufacturing-specific because residual silica, binders, seals and other module components can control corrosion behavior [16-18]. EESEF therefore does not accept a blanket “HF resistant” claim for the complete membrane system without a written chemical-compatibility specification for the exact membrane, potting, gaskets, piping and operating conditions.



Photo 4. Supplier-provided acidic feed/liquid sample. Cloudiness is visually apparent but does not identify the silicon species or concentration [13].



Photo 5. Supplier-provided laboratory column/test image showing retained/formed solids. Composition and uranium content require analytical confirmation [13].

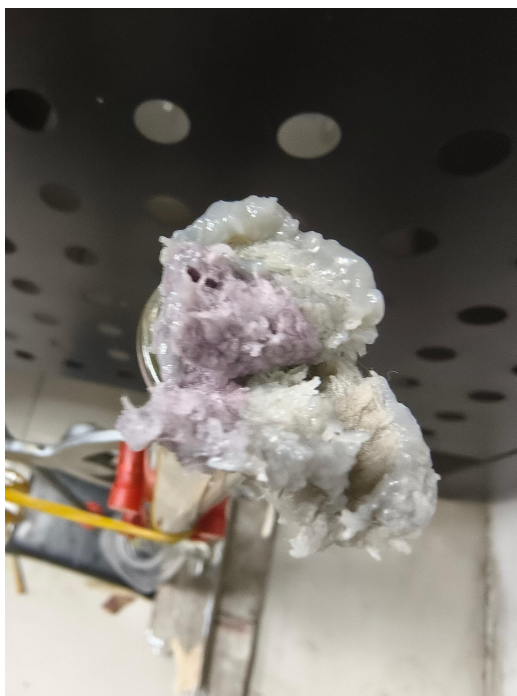


Photo 6. Supplier-provided recovered wet solid/gel-like material. Visual appearance alone cannot establish silica composition [13].



Photo 7. Supplier-provided parallel laboratory column test. The setup is useful as a qualitative process-development reference; test conditions and mass balance were not supplied [13].

7D. Revised Combined Treatment Hypothesis

The new material suggests a technically coherent combined hypothesis that should be tested rather than assumed:

- Characterize the PLS and determine how much silicon is particulate/colloidal versus operationally dissolved/reactive.
- If a significant colloidal/particulate fraction exists, test direct SiC ceramic MF/UF as a pretreatment.
- If the problematic fraction is predominantly dissolved/reactive, test controlled phase conversion/precipitation first.
- Use ceramic membrane filtration or another solid-liquid separation step to remove the newly formed silicon-bearing solids.

- Confirm uranium remains in the desired liquid phase and quantify uranium in permeate, retentate, cake/sludge, rinses and equipment hold-up.
- Only then compare treated and untreated PLS on uranium IX resin to demonstrate the downstream benefit.

Supplier proposition	EEEF assessment	Action
“Silicon compound” vs “silicate ion” are the two liquid forms	Too simplified for acidic process liquor	Use operational fractionation and, if needed, advanced speciation
Cloudy liquid indicates silica problem	Cloudiness indicates dispersed material, not composition	Measure Si fractions, TSS/turbidity and solids chemistry
SiC membrane removes silica without uranium	Plausible for particles/colloids; not established for dissolved Si or U behavior	Bench-test with full U/Si mass balance
Slow acidification / pH 2-5 promotes gel formation	Chemically plausible in general, exact operating claim unverified	Record pH history; run controlled pH/time tests
System tolerates H ₂ SO ₄ and HF	SiC can be highly acid-resistant; full-module compatibility is grade/component specific	Obtain exact chemical-compatibility certificate and test conditions

8. Technology-Transfer Gap Analysis

The key transfer question is whether a process developed for a non-uranium hydrochloric-acid stream can remove the relevant silicon fraction from sulfate-rich uranium PLS without unacceptable uranium loss or process disruption. This cannot be answered by visual clarity alone. Clear liquor may still contain dissolved silicon, and precipitated solids may contain uranium.

Every candidate technology must therefore be evaluated using the same independent criteria: removal of the targeted silicon fraction; uranium recovery/loss; pH excursion and re-acidification demand; reagent consumption; sludge mass and composition; effects on sulfate and major ions; downstream IX loading/elution; operability; materials compatibility; and waste-management implications.

Parameter	Chinese acidic-liquor reference	Kazakhstan uranium PLS	Verification significance
Acid matrix	Hydrochloric acid (supplier-reported)	Expected sulfate-dominated acid ISL liquor	Critical
Uranium	Absent / not reported	Present	Critical - U loss must be measured
Silicon form	Supplier describes substantial silica-bearing material	Unknown; characterization required	Critical
Primary objective	Clarification / reuse of acid stream	Direct Si removal before uranium IX	High
Other ions	Supplier data required	Site-specific Fe/Al/Ca/Mg/V/Mo etc.	High
Proof currently available	Supplier description + equipment images	No Kazakhstan pilot data	Critical
Transfer status	Industrial reference case	Unverified application	Pilot required

Common pilot evaluation criteria

Criterion	Why it matters
Targeted Si fraction removed	Demonstrates that treatment addresses the targeted process-liquor silicon problem
Uranium mass balance	Prevents product loss to sludge/retentate
pH / reagent demand	Determines integration and operating burden
Sludge mass and composition	Determines waste/radiological handling burden
IX loading / leakage / elution	Confirms downstream benefit
Cycle stability	Distinguishes short-term effect from durable improvement
Materials / corrosion compatibility	Essential for acidic service
Independent analytical QA/QC	Separates verified performance from supplier claims

9. Stage-Gated Bench and Pilot Program

Stage 0 - Baseline characterization: complete the analytical and sampling program and establish representative IX performance before changing the process.

Stage 1 - Bench screening: test a limited set of direct-removal mechanisms on actual PLS, including the Chinese phase-conversion approach if sufficient process information is provided. Every condition must measure feed and treated silicon fractions, uranium, pH, matrix ions, reagent dose and solids generated.

Stage 2 - Uranium protection gate: reject or modify any condition that causes material uranium transfer to sludge/retentate, unacceptable solution chemistry, excessive neutralization/re-acidification demand or disproportionate waste generation.

Stage 3 - Dynamic IX verification: compare treated PLS with untreated control through representative uranium resin under matched conditions. Track uranium loading, leakage/breakthrough, elution/wash profile, hydraulic behavior and cycle-to-cycle stability.

Stage 4 - Field pilot: only a mass-balanced bench option with demonstrated IX benefit and acceptable uranium recovery proceeds. The field pilot should include control sampling, calibrated flow/reagent metering, safe management of uranium-bearing solids and independent analytical verification.

Stage 5 - Scale-up decision: proceed only when performance is reproducible and the net technical, environmental and economic benefit is demonstrated.

10. Resin Fouling and Regeneration - Supporting Context

The Chinese supplier separately reported a resin-fouling mechanism involving ingress of low-molecular-weight silicic species, polymerization/precipitation within resin pores and deterioration of resin performance, together with partner-reported figures after repeated cycles and after NaOH regeneration [13]. Independent uranium literature supports the general phenomenon of silica fouling and the use of caustic treatment in resin management [6,7].

The supplier-reported numerical values - 13.7% saturated-capacity loss, 28.9% washing-peak reduction, approximately 9.9% capacity recovery after NaOH treatment and 99.8% reported washout - remain unpublished and unverified. They should be retained only as a replication target or illustrative supplier dataset, never as expected Kazakhstan performance. Raw test conditions and definitions are required before technical comparison.

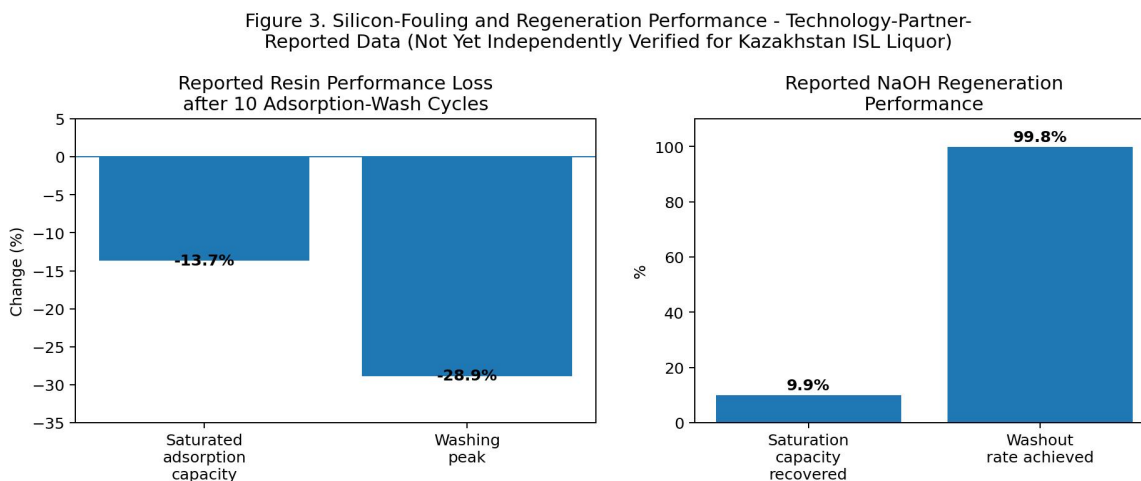


Figure 3. Supplier-reported resin performance/regeneration data. Unpublished and not independently verified; retained only as supporting context [13].

11. ESG and EEESEF Mission Alignment

EESEF's non-profit role is to support environmental science, education, research cooperation and independent technical evaluation. In this project that means clarifying an environmental/process problem, strengthening the evidence base, bringing university and industry knowledge into a transparent test framework, and avoiding commercial endorsement or financial interest in a particular technology.

The ESG relevance is strongest where it can be measured. Effective upstream silicon management may reduce resin cleaning frequency, chemical consumption, resin replacement, process interruptions and waste generation per unit of uranium recovered. It may also reduce the risk that an ineffective treatment transfers uranium into a waste solid. These are resource-efficiency, waste-management and operational-governance issues rather than marketing claims.

Kazakhstan's wider water-security context reinforces the need for careful process-water and chemical management. The World Bank identifies challenges including declining surface-water availability, transboundary dependence, water-quality pressures and limitations on economically usable groundwater [10]. This report does not claim that silicon removal will solve national water stress; it frames efficient chemical and water management as one contribution to responsible operation.

Groundwater restoration after ISL is a separate hydrogeological topic. IAEA literature documents restoration and monitored natural attenuation considerations in ISL operations, including Kazakhstan-related work [11]. The present report therefore avoids asserting a direct causal link between surface-plant silica fouling and aquifer restoration.

For sustainability reporting, operators should use the current applicable IFRS/SASB Metals & Mining requirements and clearly distinguish them from proposed amendments still under standard-setting consideration [12]. EEESEF may map verified pilot data to relevant water, waste and resource-efficiency disclosures, but should not present a pilot study itself as an ESG disclosure.

12. Recommendations

- Test the working hypothesis that an operationally significant silicon fraction is present in dissolved, colloidal or otherwise non-readily-filterable form, and verify the fraction distribution analytically before selecting equipment.
- Use paired unfiltered/filtered ICP-Si plus ASTM D859 or a validated equivalent for laboratory molybdate-reactive silica; use ASTM D7126 only for online monitoring within its scope [3,4].
- Obtain at least three representative PLS datasets and a baseline IX dataset before establishing design criteria.
- Request a complete technical data package for the Chinese acidic-liquor reference process, without relying on photographs or visual clarity as proof of silicon removal [13].
- Bench-test the Chinese phase-conversion approach, if technically disclosed, against at least one independently supported direct-removal mechanism such as magnesium-assisted precipitation and, if appropriate, a selective inorganic sorbent [8,9].
- Make uranium mass balance a mandatory go/no-go criterion for every direct-removal test.
- Measure sludge quantity, uranium content, silicon content and handling characteristics before judging a precipitation route acceptable.
- Verify the downstream benefit by comparing treated and untreated PLS on representative uranium IX resin.
- Keep resin cleaning/regeneration as supporting context, not the primary solution sought by this project.
- Maintain EEESEF's independence by describing all commercial technologies generically, separating supplier claims from independent evidence, and publishing conclusions only after site-specific verification.

13. Conclusion

The project question is now clearly defined: characterize the silicon-containing species present in Kazakhstan uranium ISL process liquor and determine whether they can be removed directly from the solution before uranium IX, without sacrificing uranium recovery or creating disproportionate chemical and waste burdens.

The available evidence supports the importance of the problem but not a preselected solution. Silica fouling of uranium IX resin is independently documented [6,7]. Laboratory standards provide a defensible route to operationally characterize the silicon fractions [3-5]. Peer-reviewed industrial-water studies provide candidate direct-removal mechanisms [8,9]. The Chinese acidic-liquor case provides a potentially relevant industrial technology-transfer precedent, but its applicability to sulfate-rich uranium PLS remains unverified [13].

EESEF's appropriate role is therefore to coordinate evidence-based characterization, independent comparison and controlled piloting. A successful outcome would not be the promotion of a particular manufacturer; it would be a reproducible, mass-balanced process demonstrating meaningful silicon reduction, preserved uranium recovery, improved IX performance and acceptable environmental/resource impacts.

References

- [1] **World Nuclear Association.** Uranium and Nuclear Power in Kazakhstan. Updated 1 July 2026. Kazakhstan produced 25,839 tU in 2025, about 40% of world output. <https://world-nuclear.org/information-library/country-profiles/countries-g-n/kazakhstan>
- [2] **World Nuclear Association.** In-Situ Leach Mining of Uranium. Overview of ISL chemistry and uranium recovery. <https://world-nuclear.org/information-library/nuclear-fuel-cycle/mining-of-uranium/in-situ-leach-mining-of-uranium>
- [3] **ASTM International.** ASTM D859-16(2021)e1, Standard Test Method for Silica in Water. Laboratory/grab-sample molybdate-reactive silica method. <https://store.astm.org/d0859-16.html>
- [4] **ASTM International.** ASTM D7126-15(2023), Standard Test Method for On-Line Colorimetric Measurement of Silica. Online method; excludes laboratory/grab samples and directs users to D859. <https://store.astm.org/d7126-15r23.html>
- [5] **Standard Methods.** Standard Methods for the Examination of Water and Wastewater, 4500-SiO₂ series. <https://www.standardmethods.org/>
- [6] **US Patent 7,655,199 B2.** Process for uranium recovery using anion exchange resin. Documents silica fouling effects on uranium IX loading/elution in high-silica sulfuric-acid leach liquor. <https://patents.google.com/patent/US7655199B2/en>
- [7] **Kotze et al.** Comparison of various anion exchange resins for the recovery of uranium by means of RIP. Journal of the Southern African Institute of Mining and Metallurgy 109 (2009). Documents silica fouling in acidic uranium sulfate liquor and resin-performance effects. <https://www.saimm.org.za/Journal/v109n10p609.pdf>
- [8] **Latour, Miranda & Blanco.** Silica removal in industrial effluents with high silica content and low hardness. Environmental Science and Pollution Research 21 (2014). <https://pubmed.ncbi.nlm.nih.gov/24777323/>
- [9] **Sasan et al.** Exceptional selectivity for dissolved silicas in industrial waters using mixed oxides. Journal of Water Process Engineering 20 (2017), 187-192. <https://doi.org/10.1016/j.jwpe.2017.11.003>
- [10] **World Bank.** Kazakhstan General Water Security Assessment (2024). National water-security, transboundary dependence, groundwater-quality and water-management context. <https://documents1.worldbank.org/curated/en/099062424121021579/pdf/P1700301c580430118aca1917d53b41c92.pdf>
- [11] **IAEA.** In Situ Leach Uranium Mining - An Overview of Operations (IAEA-TECDOC-1873) and related Kazakhstan restoration/monitoring literature. <https://www-pub.iaea.org/MTCD/Publications/PDF/TE-1873web.pdf>
- [12] **IFRS Foundation / ISSB.** SASB Standards - Metals & Mining and project to enhance SASB Standards. Current issued requirements must be distinguished from proposed amendments. <https://www.ifrs.org/projects/work-plan/enhancing-the-sasb-standards.html/>
- [13] Chinese technology supplier information provided to EEESEF. Supplier-provided description, photographs and performance statements for an industrial acidic-liquor desilication process and separate resin-fouling/regeneration observations. Unpublished and not independently verified for Kazakhstan uranium PLS. Internal technical correspondence; supplier identity intentionally omitted.

[14] Iwasaki, H.; Shimada, K.; Tarutani, T. Gel chromatographic study of the polymerization of silicic acid in acid solutions. *Journal of Chromatography A* 198 (1980) 429-434. Demonstrates polymerization in HCl, HNO₃, HClO₄ and H₂SO₄ acid solutions.

[15] Dietzel, M. Dissolution of silicates and the stability of polysilicic acid. *Geochimica et Cosmochimica Acta* 64(19) (2000) 3275-3281. At pH 3 in sulfuric solutions, both monomeric and polymeric silicic acid were observed.

[16] Brozek, V. et al. Corrosion of ceramic silicon carbide in hydrofluoric acid. *Ceramics-Silikaty* 65(2) (2021) 158-169. Shows HF resistance depends on SiC purity, residual SiO₂ and binder chemistry.

[17] Saint-Gobain Performance Ceramics & Refractories. Crystar filtration technology / chemical recovery technical information. High-purity recrystallized SiC is reported for corrosive acid/caustic filtration across a broad pH range; application-specific module compatibility remains necessary.

[18] Mersen. CORROSIC silicon carbide corrosion-resistance technical information. Pressureless-sintered SiC is reported resistant to common acids including H₂SO₄ and HF; complete-system compatibility must still consider seals and ancillary materials.

Annex A - Evidence Status of Key Project Statements

Statement	Status
Working hypothesis: operationally significant Si may include a dissolved, colloidal or otherwise non-readily-filterable fraction	Stakeholder working assessment; requires analytical verification
Exact silicon species in Kazakhstan PLS	Unknown at report date; characterization required
Silica fouling can impair uranium IX	Established external evidence [6,7]
Chinese acidic-liquor desilication package exists	Supplier-provided evidence [13]
Chinese process works on Kazakhstan uranium PLS	Not established; bench/pilot verification required
Partner resin figures 13.7%, 28.9%, 9.9%, 99.8%	Supplier-reported, unpublished and unverified [13]
Supplier claim: two liquid silicon forms only	Not adopted; chemically oversimplified [14,15]
Supplier claim: SiC membrane removes silicon without uranium	Unverified; plausible only for retained particles/colloids until mass balance proves otherwise
Supplier claim: pH history drives silica gel formation	Plausible hypothesis; exact thresholds require site testing [14,15]
Supplier claim: complete system tolerates HF	Requires exact material/module compatibility documentation [16-18]
Proposed small-scale experimental treatment unit for evaluation	Supplier-proposed experimental platform; performance on Kazakhstan uranium-bearing process liquor not yet independently established [13]

Annex B - Minimum Data Request for Chinese Technology

- Feed and treated silicon concentration, analytical method and reporting units
- Feed/treated pH and full acid/matrix composition
- Reagent identities, concentrations, doses and sequence
- Residence time, temperature, mixing and solids-separation conditions
- Throughput and turndown
- Sludge mass, composition and dewatering characteristics
- Materials of construction and corrosion basis
- Operating history and number of industrial installations
- Mass balance and independently verifiable performance data
- Proposed test protocol for Kazakhstan uranium PLS, including uranium-loss controls
- Exact SiC membrane grade, purity, pore-size distribution and nominal/absolute cut-off
- Membrane area, clean-water permeability and design flux
- TMP and cross-flow velocity range
- Compatibility limits for H₂SO₄, HF and mixtures at stated concentration/temperature

- Seal, gasket, potting and piping materials
- Backwash/CIP chemistry and expected flux recovery
- Particle-size / silica rejection data and analytical method
- Uranium passage/retention and adsorption data, if any
- Retentate concentration factor and solids-management plan

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Sign-Off and Closing Block

APPROVAL FOR PUBLICATION

This technical report has been reviewed and approved for publication by the Euro-Eurasia Environmental Science & Education Foundation (EEEESEF).

Gelu Negreanu

Founder & Chairman

Euro-Eurasia Environmental Science & Education Foundation (EEEESEF)

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