

Supporting Information for

EFFECT OF ISA AND CHLORIDE ON THE UPTAKE OF NIOBIUM(V) BY HARDENED CEMENT PASTE AND C-S-H PHASES: QUANTITATIVE DESCRIPTION AND MECHANISTIC UNDERSTANDING

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1. Supporting Information for Experimental Section

1.1. NMR characterization of ISA used in this work

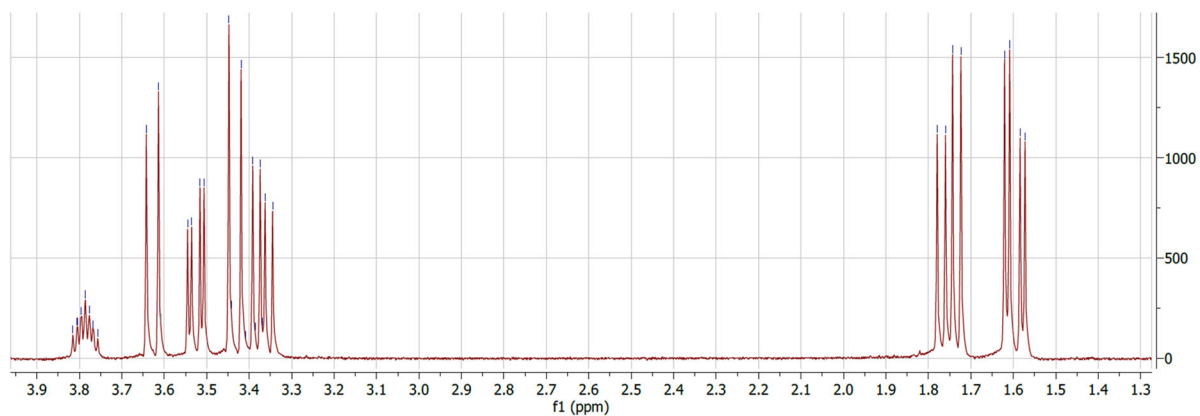


Figure SI-1. ^1H NMR spectra of isosaccharinic acid solution with $[\text{ISA}] = 0.02 \text{ M}$ prepared from ISA-lactone in 0.1 M NaOH .

1.2. Separation of niobium isotopes from the irradiated Zr foil

The irradiated Zr foil was placed and dissolved in a solution containing 1.5 mL of Milli-Q water and 0.6 mL of 48 % HF. The dissolution was conducted in Teflon FEP centrifugal tubes immersed in ice to avoid the evaporation of the solution due to the reaction heat. Additional 3.9 mL of 48 % HF were added after the total dissolution of the Zr foil. 300 mg of DOWEX® 50X8 resin (50–100 mesh) were soaked for 30 min, and later transferred into a PP + PE column. Additional 2 mL of 48 % HF were used to rinse the resin in the column. The solution containing active Zr and Nb was passed through the DOWEX® 50X8 column, and the column was washed with fresh 3 mL of 48 % HF. Undesired divalent and trivalent cations and particulates were collected in the DOWEX® 50X8 resin, whereas anionic Nb- and Zr-fluoride complexes remained in the aqueous phase (“1st eluate”) [1-3].

600 mg of DOWEX 1X8 (200–400 mesh) were soaked in 4 mL of 48% HF for 30 min, transferred into a new PP + PE column, and washed with additional 4 mL of 48% HF. The 1st eluate was passed through the DOWEX 1X8 column, and the resin was washed with additional 18 mL of 48 % HF. In this process, Nb was retained in the DOWEX 1X8 resin and Zr was removed with the eluate [4]. After the elution, the resin was washed with 2 mL of 1 M HCl in order to remove the HF remains from the resin, and afterwards Nb in the column was eluted using a 2 mL solution of 6 M HCl and 1 % H₂O₂. The eluate with Nb was collected and heated at about 120 °C to remove H₂O₂ for 10 min, and then 2.1 mL of 37% HCl were added in the remaining solution (“Nb-HCl solution”).

300 mg of UTEVA resin (TRISKEM) were soaked into the 2 mL 37 % HCl for 30 min. The mixture of UTEVA and HCl was transferred into a new PP + PE column. The column was washed with additional 2 mL of 37 % HCl. The Nb-HCl solution was passed through the UTEVA column, and the column was washed with 90 mL of 5.5 M HCl, which removed the trace amounts of Zr remaining in the column. Afterwards, the Nb retained in the column was eluted with 36 mL of 2 M HCl. These HCl concentrations were optimized to separate Zr and

Nb with UTEVA resin [5]. The final eluate was evaporated to dryness. To remove organic materials possibly leached from the resins, the residue was dissolved in 10 mL of 8 M HNO₃, boiled, and evaporated to dryness. The final Nb solution was obtained by the dissolution of the residue in 10 mL 2 % HNO₃. During the separation, dryness of resins before completing elution was avoided. All separation procedures were conducted in the glove box with filter, ventilation, and lead blocks. The separation scheme is provided in Fig. SI-2.

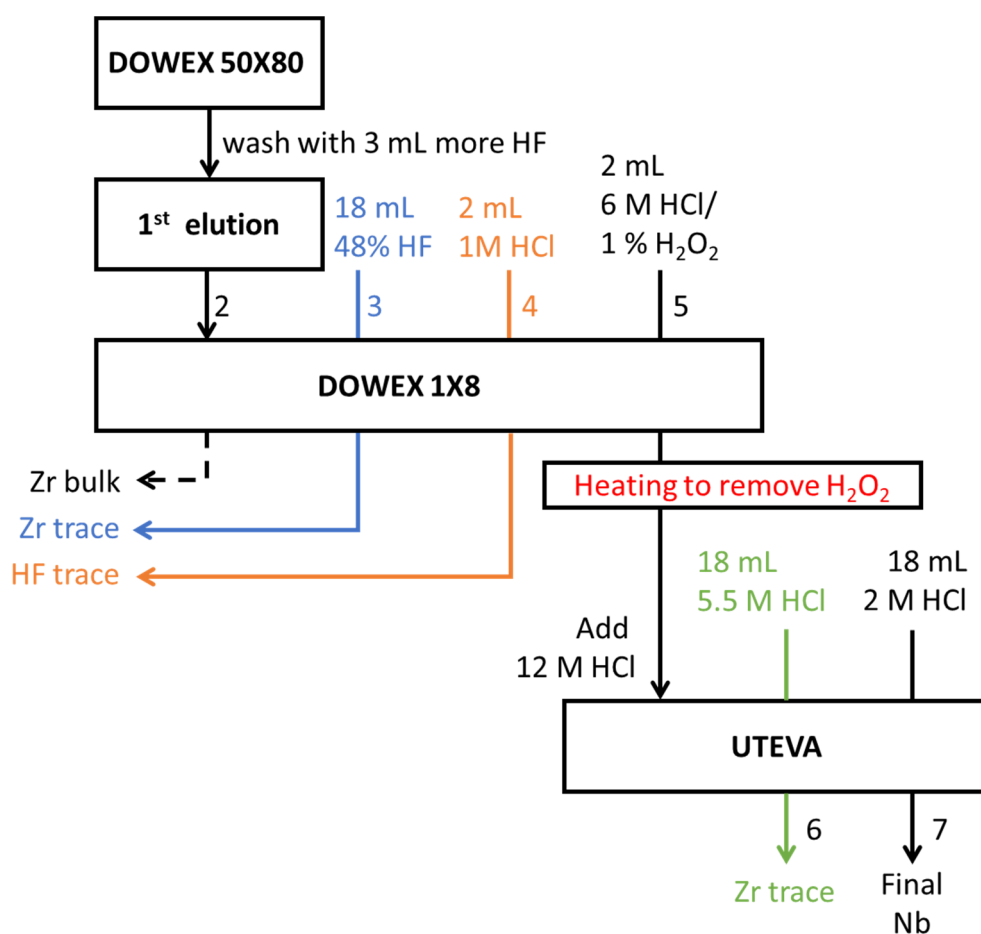
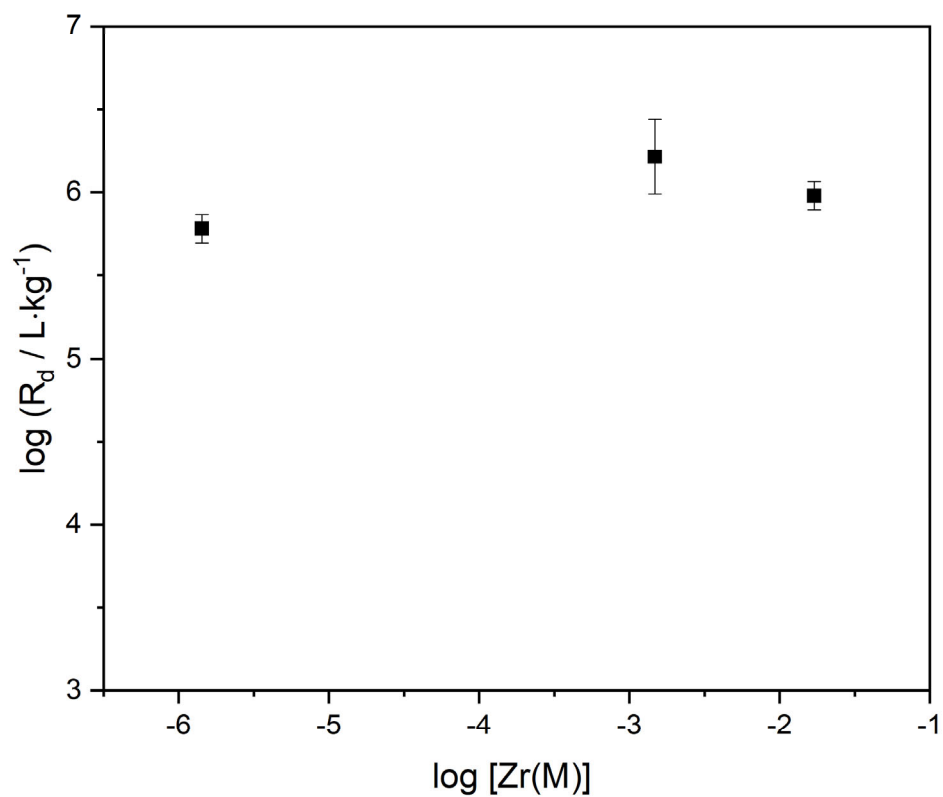


Figure SI-2. Scheme of the procedure used in this work for the separation of active Nb isotopes from the irradiated Zr foil.

47 1.3. Zr effect on Nb sorption



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49 **Figure SI-3.** Effect of Zr concentration on the uptake of Nb by C-S-H phases with Ca:Si =
 50 1.4. ($[^{95}Nb]_0 = 10^{-10} M$; $S:L = 0.5 g \cdot L^{-1}$; $t = 5$ days).

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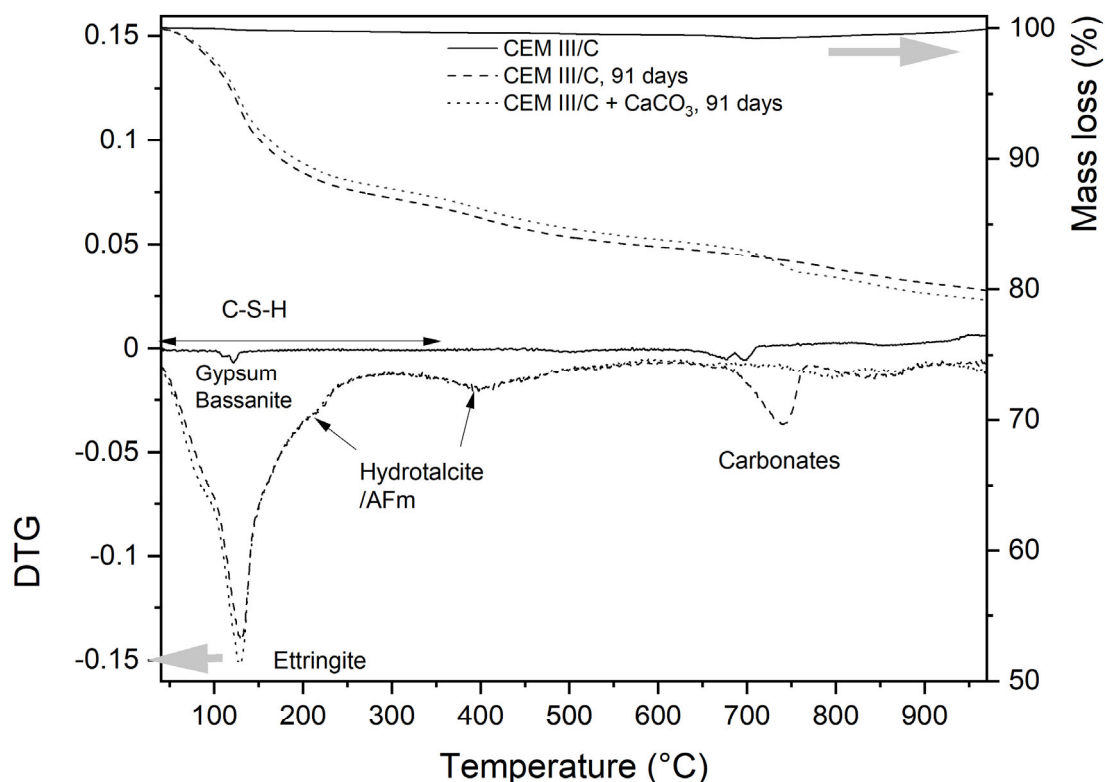
1.4. Unhydrated cement

Table SI-1. Composition of the CEM III/C cement used in this work. The elemental composition was determined by XRD, whereas the phase composition was determined by XRD with Rietveld analysis.

	Chemical composition (g/100 g)		Phase composition (g/100 g)
SiO ₂	32.31	Amorphous	88.4
Al ₂ O ₃	9.33	Alite	5.9
Fe ₂ O ₃	0.65	Belite	0.5
Cr ₂ O ₃	< 0.003	Aluminate	0.5
MnO	0.222	Ferrite	0.4
TiO ₂	0.636	Anhydrite	3.5
P ₂ O ₅	0.08	Hemihydrate	0.3
CaO	45.28	Gypsum	0.2
MgO	7.27	Calcite	0.6
K ₂ O	0.52	Quartz	0.1
Na ₂ O	0.26	Gehlenite	0.2
SO ₃	3.39		
Cl ⁻ *	0.026		
Loss on ignition	0.17		
Total C	0.15		
Organic C	0.09		
Inorganic C	0.06		
CO ₂	0.22		

*Reported as total chloride determined from dissolution of the cement

The amount of slag in CEM III/C was determined as 84 wt.% according to Sylla and Sybertz [7]. Determination of the amount of slag is based on counting the fraction of slag and clinker particles in a sub sample (diameter 32-40 µm) of the cement using an optical microscope and a correction based on the measured XRF composition of the sub-sample and the unfractionated cement. The slag content determined by XRD with Rietveld analysis corresponded to 88 wt.%.



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Figure SI-4. Thermogravimetric analysis and differential weight loss (DTG) of the unhydrated CEM III/C cement used in this work as well as of the CEM III/C and CEM III/C+5wt% CaCO₃ hydrated for 91 days. The small weight gain of the unhydrated CEM III/C cement above 700°C is due to the oxidation of S(-II) contained in the slag [8].

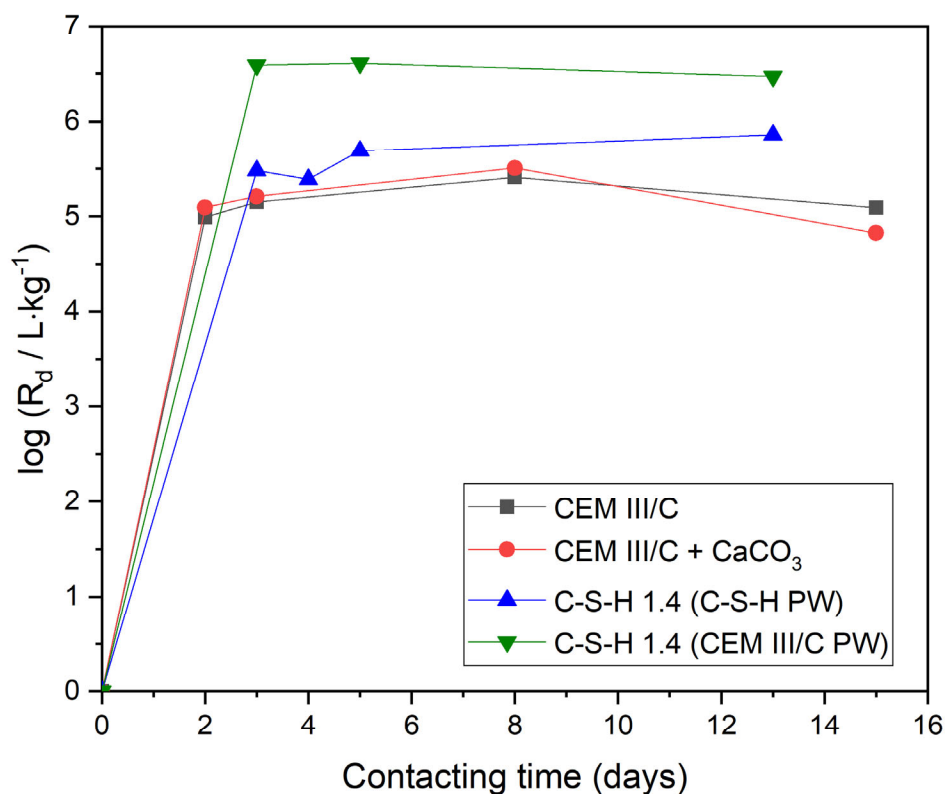
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The degree of reaction of the slag after 91 days was estimated by selective dissolution of the unhydrated and hydrated CEM III/C cement mixes using a buffered solution of EDTA, triethanolamine and diethanolamine as recommended in the RILEM TC 238-SCM committee [9], which is used to dissolve the anhydrous cement and the hydrates but not the unreacted slag, nor hydrotalcite. The slag reaction degrees (corrected for undissolved hydrotalcite according to [9]) gave a reaction degree of 13% for limestone free sample and of 31% for the limestone containing CEM III/C + CaCO₃ CEM III/C. The presence of limestone is known to accelerate the slag reaction [10] as it lowers the Al concentration in the pore solution, one of the main factors (in addition to low pH) slowing the reaction of siliceous glasses [11, 12]. Based on the measured slag reaction degree after 91 days and different studies in literature [10, 13, 14], a reaction degree of around 50wt.% can be expected to be in the samples hydrated for 1.5 years.

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88 2. Supporting Information for Results and Discussion Section

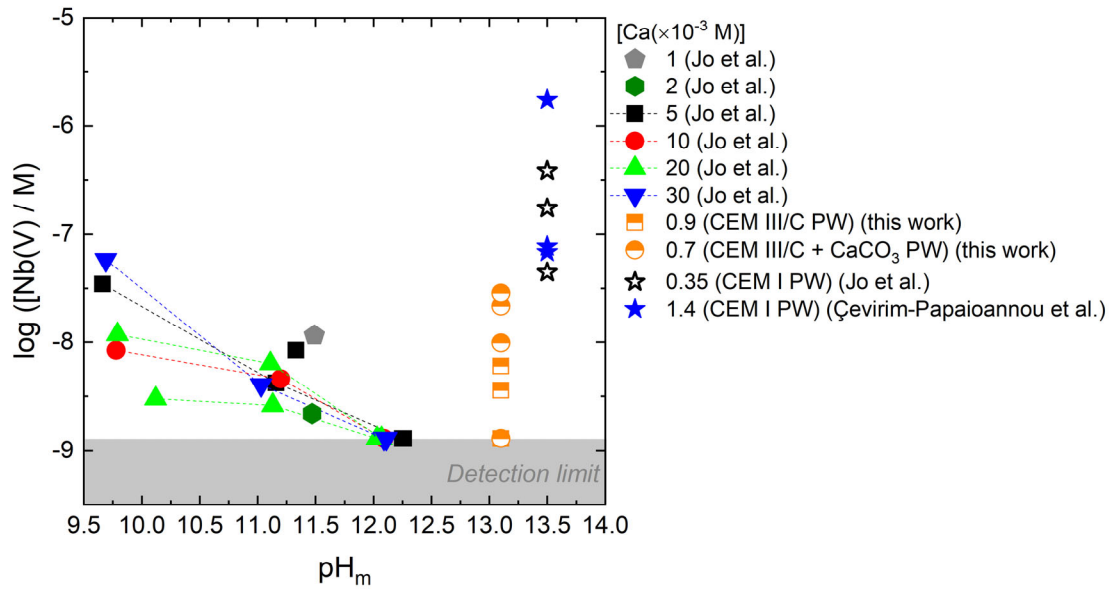


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 90 **Figure SI-5.** Sorption kinetics for the uptake of Nb(V) by HCP (CEM III/C and CEM III/C +
 91 CaCO₃) and C-S-H phases with Ca:Si = 1.4. Experimental conditions: $[^{95}\text{Nb}]_0 = 10^{-10} \text{ M}$, $S:L$
 92 = $0.5 \text{ g}\cdot\text{L}^{-1}$). PW: porewater in equilibrium with hardened cement paste.

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97 **Figure SI-6.** Solubility of Nb(V) in cementitious porewater solutions containing different Ca
 98 concentrations, as determined in this work or reported in the literature, i.e., Jo et al. (2022)[15]
 99 and Çevirim-Papaioannou et al. (2022) [16]. Ca concentrations at $pH > 13$ are mostly $< 10^{-3}$
 100 M. PW: porewater in equilibrium with hardened cement paste.

Table SI-2. Data table of figure 2 (colors correspond to the color of the symbols in the figure)

HCP type	S:L (g·L ⁻¹)	[Nb] _{tot} (M)	[Cl] _{tot} * (M)	Contacting time (days)	log (C _{aq} /mol·L ⁻¹)	uncertainty	log (C _{solid} /mol·kg ⁻¹)	uncertainty
CEM III/C	0.5	5.00×10 ⁻⁹	2.41×10 ⁻³	5	-10.45	0.24	-4.08	0.01
CEM III/C	0.5	1.00×10 ⁻⁸	2.41×10 ⁻³	5	-10.07	0.35 [†]	-4.04	0.35 [†]
CEM III/C	0.5	1.00×10 ⁻⁷	2.41×10 ⁻³	5	-9.23	0.35 [†]	-3.66	0.35 [†]
CEM III/C	0.5	1.00×10 ⁻⁶	2.41×10 ⁻³	5	-7.69	0.35 [†]	-2.83	0.35 [†]
CEM III/C	0.5	1.00×10 ⁻⁵	2.41×10 ⁻³	5	-6.75	0.35 [†]	-1.85	0.35 [†]
CEM III/C + CaCO ₃	0.5	5.00×10 ⁻⁹	6.47×10 ⁻³	5	-10.38	0.35	-4.05	0.01
C-S-H 1.4 (CEM III/C PW)	0.5	3.04×10 ⁻¹¹	2.41×10 ⁻³	5	-13.77	0.07	-6.92	0.00
C-S-H 1.4 (CEM III/C PW)	0.5	3.84×10 ⁻⁸	2.41×10 ⁻³	5	-10.76	0.07	-3.80	0.00
C-S-H 1.4 (C-S-H PW)	0.5	9.13×10 ⁻¹¹	0	5	-12.65	0.09	-6.57	0.00
C-S-H 1.4 (C-S-H PW)	0.5	5.06×10 ⁻⁷	0	5	-9.39	0.09	-2.95	0.00
C-S-H 1.4 (C-S-H PW)	0.5	5.54×10 ⁻⁶	0	5	-8.11	0.19	-1.91	0.00
C-S-H 1.4 (C-S-H PW)	0.5	5.57×10 ⁻⁵	0	5	-7.72	0.01	-0.89	0.00
C-S-H 1.4 (C-S-H PW)	0.5	5.60×10 ⁻⁴	0	5	-6.49	0.06	0.10	0.00
C-S-H 1.4 (C-S-H PW)	0.5	5.58×10 ⁻³	0	5	-4.94	0.13	1.10	0.00
CEM III/C (only ⁹³ Nb)	0.5	9.10×10 ⁻⁶	2.41×10 ⁻³	5	-7.57	-	-1.88	-
CEM III/C (only ⁹³ Nb)	0.5	4.99×10 ⁻⁵	2.41×10 ⁻³	5	-6.83	-	-1.15	-
CEM III/C (only ⁹³ Nb)	0.5	5.01×10 ⁻⁵	2.41×10 ⁻³	5	-6.85	-	-1.14	-
CEM III/C (only ⁹³ Nb)	0.5	1.00×10 ⁻⁴	2.41×10 ⁻³	5	-6.75	-	-0.84	-
CEM III/C (only ⁹³ Nb)	0.5	9.99×10 ⁻⁵	2.41×10 ⁻³	5	-6.71	-	-0.84	-
CEM III/C (only ⁹³ Nb)	0.5	3.91×10 ⁻⁷	2.41×10 ⁻³	5	-8.14	0.21	-3.55	0.02
CEM III/C (only ⁹³ Nb)	0.5	2.58×10 ⁻⁵	2.41×10 ⁻³	43	-7.84	-	0.04	-

CEM III/C (only ⁹³ Nb)	0.5	4.91×10 ⁻⁵	2.41×10 ⁻³	43	-7.94	-	0.07	-
CEM III/C (only ⁹³ Nb)	0.5	9.62×10 ⁻⁵	2.41×10 ⁻³	43	-7.52	-	0.14	-
CEM III/C (only ⁹³ Nb)	0.5	5.38×10 ⁻⁴	2.41×10 ⁻³	43	-7.22	-	0.78	-
CEM III/C (only ⁹³ Nb)	0.5	1.05×10 ⁻³	2.41E-03	43	-7.07	-	1.52	-
C-S-H 1.4 (C-S-H PW) (only ⁹³ Nb)	0.5	5.60E-05	0.00E+00	43	-8.54	-	-1.01	-

*[Cl] = 2.41×10⁻³ M and 6.47×10⁻³ M in CEM III PW and CEM III+CaCO₃ PW

†Uncertainty for log (C_{aq}/mol·L⁻¹) and log (C_{solid}/mol·kg⁻¹) for the samples whose only one measurement was available was assumed to be 0.35, which was the maximum uncertainties obtained from replicated samples. The uncertainty was not given for the samples using ⁹³Nb whose only one measurement was available.

Table SI-3. Calculated and measured concentrations of Ca resulting from the dissolution of CaO in HCP by increasing concentrations of ISA.

S:L (g·L ⁻¹)	Calculated %					Measured %					
	log [ISA(M)]					log [ISA(M)]					
	-5	-4	-3	-2	-1	-5	-4	-3	-2	-1.5	-1
0.5	0.7	0.8	1.7	10.8	66.2	0	0	0	10.0	n.d	64.0
1	0.4	0.4	0.9	5.4	33.1	0	0	0	7.6	21.5	51.6
2	0.2	0.2	0.4	2.7	16.5	0	0	0	0	19.1	40.1

n.d.: not determined

110 **Table SI-4. Data table of figure 4 (colors correspond to the color of the symbols in the figure)**

HCP type	S:L (g·L ⁻¹)	[Nb] _{tot} (M)	[ISA] _{tot} (M)	[Cl] _{tot} (M)*	log (R _d /L·kg ⁻¹)	uncertainty	order of addition
CEM III/C	0.5	5.00×10 ⁻⁹	0	2.41×10 ⁻³	5.66	0.51	no ISA, reference line
CEM III/C	0.5	5.00×10 ⁻⁹	1.00×10 ⁻⁵	2.41×10 ⁻³	6.19	0.51 [†]	(Nb+cem)+ISA
CEM III/C	0.5	5.00×10 ⁻⁹	1.00×10 ⁻⁴	2.41×10 ⁻³	5.61	0.51 [†]	(Nb+cem)+ISA
CEM III/C	0.5	5.00×10 ⁻⁹	1.00×10 ⁻³	2.41×10 ⁻³	5.00	0.51 [†]	(Nb+cem)+ISA
CEM III/C	1	5.00×10 ⁻⁹	1.00×10 ⁻³	2.41×10 ⁻³	4.75	0.35 [†]	(Nb+cem)+ISA
CEM III/C	1	5.00×10 ⁻⁹	3.16×10 ⁻³	2.41×10 ⁻³	4.96	0.35 [†]	(Nb+cem)+ISA
CEM III/C	1	5.00×10 ⁻⁹	1.00×10 ⁻²	2.41×10 ⁻³	4.51	0.35	(Nb+cem)+ISA
CEM III/C	1	5.00×10 ⁻⁹	3.16×10 ⁻²	2.41×10 ⁻³	4.19	0.05	(Nb+cem)+ISA
CEM III/C	1	5.00×10 ⁻⁹	1.00×10 ⁻¹	2.41×10 ⁻³	3.58	0.07	(Nb+cem)+ISA
CEM III/C	0.5	5.00×10 ⁻⁹	1.00×10 ⁻²	2.41×10 ⁻³	3.44	0.51 [†]	(Nb+ISA)+cem
CEM III/C	0.5	5.00×10 ⁻⁹	1.00×10 ⁻¹	2.41×10 ⁻³	No sorption‡	No sorption‡	(Nb+ISA)+cem
CEM III/C	2	5.00×10 ⁻⁹	3.16×10 ⁻²	2.41×10 ⁻³	3.65	0.04	(Nb+cem)+ISA
CEM III/C	2	5.00×10 ⁻⁹	1.00×10 ⁻¹	2.41×10 ⁻³	3.46	0.03	(Nb+cem)+ISA
CEM III/C + CaCO ₃	0.5	5.00×10 ⁻⁹	0	6.47×10 ⁻³	5.54	0.39	no ISA
CEM III/C + CaCO ₃	0.5	5.00×10 ⁻⁹	1.00×10 ⁻⁵	6.47×10 ⁻³	5.47	0.39 [†]	(Nb+cem)+ISA
CEM III/C + CaCO ₃	0.5	5.00×10 ⁻⁹	1.00×10 ⁻²	6.47×10 ⁻³	4.79	0.39 [†]	(Nb+cem)+ISA
CEM III/C + CaCO ₃	0.5	5.00×10 ⁻⁹	1.00×10 ⁻¹	6.47×10 ⁻³	2.80	0.39 [†]	(Nb+cem)+ISA, in brackets

111 *[Cl] = 2.41×10⁻³ M and 6.47×10⁻³ M in CEM III PW and CEM III+CaCO₃ PW

112 [†]Uncertainty for log (R_d/L·kg⁻¹) for the samples whose only one measurement was available was assumed to be 0.51, 0.35, and 0.39, which were the maximum uncertainties
113 obtained from replicated samples in each system.

114 [‡]This experimental point falls outside the experimental window of the system. It contains the highest concentration of ISA and the lowest S:L ratio, for which almost full dissolution
115 of the C-S-H phases in HCP is thermodynamically predicted.

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118 **Table SI-5. Data table of figure 6 (colors correspond to the color of the symbols in the figure)**

HCP type	S:L (g·L ⁻¹)	[Nb] _{tot} (M)	[ISA] _{tot} (M)	[Cl] _{tot} (M)*	log (R _d /L·kg ⁻¹)	uncertainty	order of addition
CEM III/C	0.5	5.00×10 ⁻⁹	0	2.41×10 ⁻³ *	5.66	0.51	No ISA
CEM III/C	0.5	5.00×10 ⁻⁹	0	1.00×10 ⁻²	6.00	0.51 [†]	No ISA
CEM III/C	0.5	5.00×10 ⁻⁹	0	1.00×10 ⁻¹	6.12	0.51 [†]	No ISA
CEM III/C	0.5	5.00×10 ⁻⁹	0	1	5.49	0.51 [†]	No ISA
CEM III/C	0.5	5.00×10 ⁻⁹	0	2	6.30	0.51 [†]	No ISA
CEM III/C	1	5.00×10 ⁻⁹	3.16×10 ⁻²	2.41×10 ⁻³ *	4.19	0.05	(Nb+cem+Cl)+ISA
CEM III/C	1	5.00×10 ⁻⁹	3.16×10 ⁻²	1.00×10 ⁻²	3.85	0.51 [†]	(Nb+cem+Cl)+ISA
CEM III/C	1	5.00×10 ⁻⁹	3.16×10 ⁻²	1.00×10 ⁻¹	3.68	0.51 [†]	(Nb+cem+Cl)+ISA
CEM III/C	1	5.00×10 ⁻⁹	3.16×10 ⁻²	1	3.87	0.51 [†]	(Nb+cem+Cl)+ISA
CEM III/C	1	5.00×10 ⁻⁹	3.16×10 ⁻²	2.07	3.61	0.51 [†]	(Nb+cem+Cl)+ISA
CEM III/C + CaCO ₃	0.5	5.00×10 ⁻⁹	0	6.47×10 ⁻³ *	5.54	0.39	No ISA
CEM III/C + CaCO ₃	0.5	5.00×10 ⁻⁹	0	1.39×10 ⁻²	5.82	0.39 [†]	No ISA
CEM III/C + CaCO ₃	0.5	5.00×10 ⁻⁹	0	1.04×10 ⁻²	6.20	0.39 [†]	No ISA
CEM III/C + CaCO ₃	0.5	5.00×10 ⁻⁹	0	2	5.74	0.39 [†]	No ISA
CEM III/C + CaCO ₃	1	5.00×10 ⁻⁹	3.16×10 ⁻²	1.00×10 ⁻²	3.89	0.39 [†]	(Nb+cem+Cl)+ISA
CEM III/C + CaCO ₃	1	5.00×10 ⁻⁹	3.16×10 ⁻²	1.00×10 ⁻²	3.94	0.39 [†]	(Nb+cem+Cl)+ISA
CEM III/C + CaCO ₃	1	5.00×10 ⁻⁹	3.16×10 ⁻²	2	3.90	0.39 [†]	(Nb+cem+Cl)+ISA

119 *[Cl] = 2.41×10⁻³ M and 6.47×10⁻³ M in CEM III PW and CEM III+CaCO₃ PW

120 [†]Uncertainty for log (R_d/L·kg⁻¹) for the samples whose only one measurement was available was assumed to be 0.51, and 0.39 for CEM III/C and CEM III/C + CaCO₃, respectively,
121 which were the maximum uncertainties obtained from replicated samples in each system.
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References

- [1] J.S. Erskine, M.L. Sink, L.P. Varga, Solvent extraction separation of tantalum and niobium fluorides with N-Benzoyl-N-Phenylhydroxylamine, *Anal Chem*, 41 (1969) 70-&.
- [2] O.L. Keller, Identification of complex ions of niobium(V) in hydrofluoric acid solutions by raman and infrared spectroscopy, *Inorg Chem*, 2 (1963) 783.
- [3] J.E. Land, C.V. Osborne, Formation constants of niobium fluoride system, *J Less-Common Met*, 29 (1972) 147.
- [4] W.G. Faix, R. Caletka, V. Krivan, Element distribution coefficients for hydrofluoric-acid nitric acid-solutions and the anion-exchange resin Dowex 1x8, *Anal Chem*, 53 (1981) 1719-1721.
- [5] V. Radchenko, D.V. Filosofov, O.K. Bochko, N.A. Lebedev, A.V. Rakhimov, H. Hauser, M. Eisenhut, N.V. Aksenov, G.A. Bozhikov, B. Ponsard, F. Roesch, Separation of Nb-90 from zirconium target for application in immuno-PET, *Radiochim Acta*, 102 (2014) 433-442.
- [6] JCPDS, Powder diffraction files, Joint Committee on Powder Diffraction Standards, Swarthmore, USA, 2001.
- [7] H.M. Sylla, F. Sybertz, Determination of the percentage of granulated blastfurnace slag in Portland slag cements and blastfurnace cements, *Zkg International*, 49 (1996) 108-&.
- [8] S.A. Bernal, M.C.G. Juenger, X. Ke, W. Matthes, B. Lothenbach, N. De Belie, J.L. Provis, Characterization of supplementary cementitious materials by thermal analysis, *Materials and Structures*, 50 (2017) 1-12.
- [9] Y.A. Villagrán-Zaccardi, A. Vollpracht, E. Gruyaert, N. De Belie, Recommendation of RILEM TC 238-SCM: determination of the degree of reaction of siliceous fly ash and slag in hydrated cement paste by the selective dissolution method, *Materials and Structures*, 51 (2018) 27.
- [10] S. Adu-Amankwah, M. Zajac, C. Stabler, B. Lothenbach, L. Black, Influence of limestone on the hydration of ternary slag cements, *Cement Concrete Res*, 100 (2017) 96-109.
- [11] M. Bagheri, B. Lothenbach, M. Shakoorioskooie, K. Scrivener, Effect of different ions on dissolution rates of silica and feldspars at high pH, *Cement Concrete Res*, 152 (2022) 106644.
- [12] R. Snellings, Solution-controlled dissolution of supplementary cementitious material glasses at pH 13: the effect of solution composition on glass dissolution rates, *Journal of the American Ceramic Society*, 96 (2013) 2467-2475.
- [13] B. Lothenbach, G. Le Saout, M. Ben Haha, R. Figi, E. Wieland, Hydration of a low-alkali CEM III/B-SiO₂ cement (LAC), *Cement Concrete Res*, 42 (2012) 410-423.

- 156 [14] V. Kocaba, E. Gallucci, K. Scrivener, Methods for determination of degree of reaction of
157 slag in blended cement pastes, *Cement Concrete Res*, 42 (2012) 511-525.
- 158 [15] Y. Jo, K. Garbev, N. Cevirim-Papaioannou, O.D. Blanco, B. de Blochouse, M. Altmaier,
159 X. Gaona, Solubility of niobium(V) in cementitious systems relevant for nuclear waste
160 disposal: characterization of the solubility-controlling solid phases, *Journal of Hazardous*
161 *Materials*, (2022) 129810.
- 162 [16] N. Çevirim-Papaioannou, Y. Jo, K. Franke, M. Fuss, B. de Blochouse, M. Altmaier, X.
163 Gaona, Uptake of niobium by cement systems relevant for nuclear waste disposal: Impact of
164 ISA and chloride, *Cement Concrete Res*, 153 (2022) 106690.

165