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ANALYSIS OF BWIP SCR COMPARISON
OF MPC TO SOLUBILITY OF
ACTINIDE COMPOUNDS

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Maximum Permissible Concentration (MPC)

The calculations presented in Section 6.4.1 and Figure 6-15 of the SCR make use of outdated MPC data (NRC, 1981). The basis for the MPC values published in Appendix B of 10 CFR Part 20 are outdated with the release of new ICRP values (ICRP Publication 30). We have made a preliminary estimate of the adjusted MPCs on the basis of the new ICRP-30 data and compare these to the old values in Appendix B of 10 CFR Part 20 (Table 3). The calculation assumes an average daily water intake of 2200 cm^3 and a factor of 10 for nonoccupational exposures. In every case, the adjusted values are more restrictive by about 1 to 2 orders of magnitude. Thus, this adjustment will raise the solubility to MPC ratio in Table 6-15 of the SCR by 1 to 2 orders of magnitude.[1]

As noted in the introduction, comparisons of solubilities to MPC are only indirectly useful since NRC 10 CFR Part 60 and EPA 40 CFR Part 191, not NRC 10 CFR Part 20 are applicable for establishing postclosure constraints on releases from high-level waste repositories.

The Maximum Permissible Concentrations for the isotopes of U, Np, Pu, and Am considered in the SCR in uncontrolled discharge (in terms of moles/liter) are presented in Table 4. The data for the initial inventory, the inventory at 1,000 years, and for Ci/mole are from Wood and Rai (1981), the reference used in the SCR estimates. The moles/liter for the nuclides are calculated assuming isotopic equilibrium (as they were in Wood and Rai, 1981). The moles/liter calculations also account for the new ICRP-30 data.

3.3 Solubility Data

The calculations presented in Section 6.4.1 and Figure 6-15 of the SCR are misleading in that they do not discuss how the lack of consideration of carbonate complexation might affect their calculations. A review of current literature (Allard, 1982) and experimental work on the actinides (Cleveland, 1982) indicate that the complexation of actinides by carbonate greatly increases actinide solubilities.

[1]NRC staff are currently revising Appendix B of 10 CFR 20. They will account for health effects on children in the population. This will result in smaller MPC values than the ones presented here.

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Allard has recently summarized literature on the solubilities of actinides in neutral or basic solutions. He has calculated solubilities of U, Np, Pu, and Am in the pH range 5-11 for oxidizing and reducing conditions in the presence of carbonate. The results of the Allard calculations are presented in Figures 2 and 3. The relevant solubility values for the oxidizing and reducing cases are selected from these figures at pH 9.5 and are divided by the corrected MPC values (Table 5) so that they can be compared to the calculations presented in Figure 6-15 of the SCR. Allard estimated the solubilities for a total carbonate concentration of 7.9×10^{-3} M and for Eh = +0.26 volt (oxidizing case) and for Eh = -0.36 volt (reducing case). These values are comparable to values for Hanford groundwaters reported in the SCR: total carbonate concentration of about 2.6×10^{-3} M; Eh = +0.22 to -0.45 volt.

Comparison of the solubility to MPC ratios presented in the BWIP SCR with Allard solubilities to MPC (adjusted from ICRP 30) indicate large apparent discrepancies. These discrepancies were identified for all the nuclides of Am, Pu, Np, and U reported in the BWIP SCR for both oxidizing and reducing conditions (Table 6). Most of the ratios differed by 5 or more orders of magnitude, a level of disagreement which would introduce an unacceptable level of uncertainty and risk into contaminant release scenarios.

The Allard (1982) estimates of solubility are also subject to considerable uncertainty because: (1) best estimates were made for key thermodynamic data where none exist; and (2) there remains considerable disagreement among reported values for key thermodynamic data. Many of these discrepancies are discussed in Allard (1982).

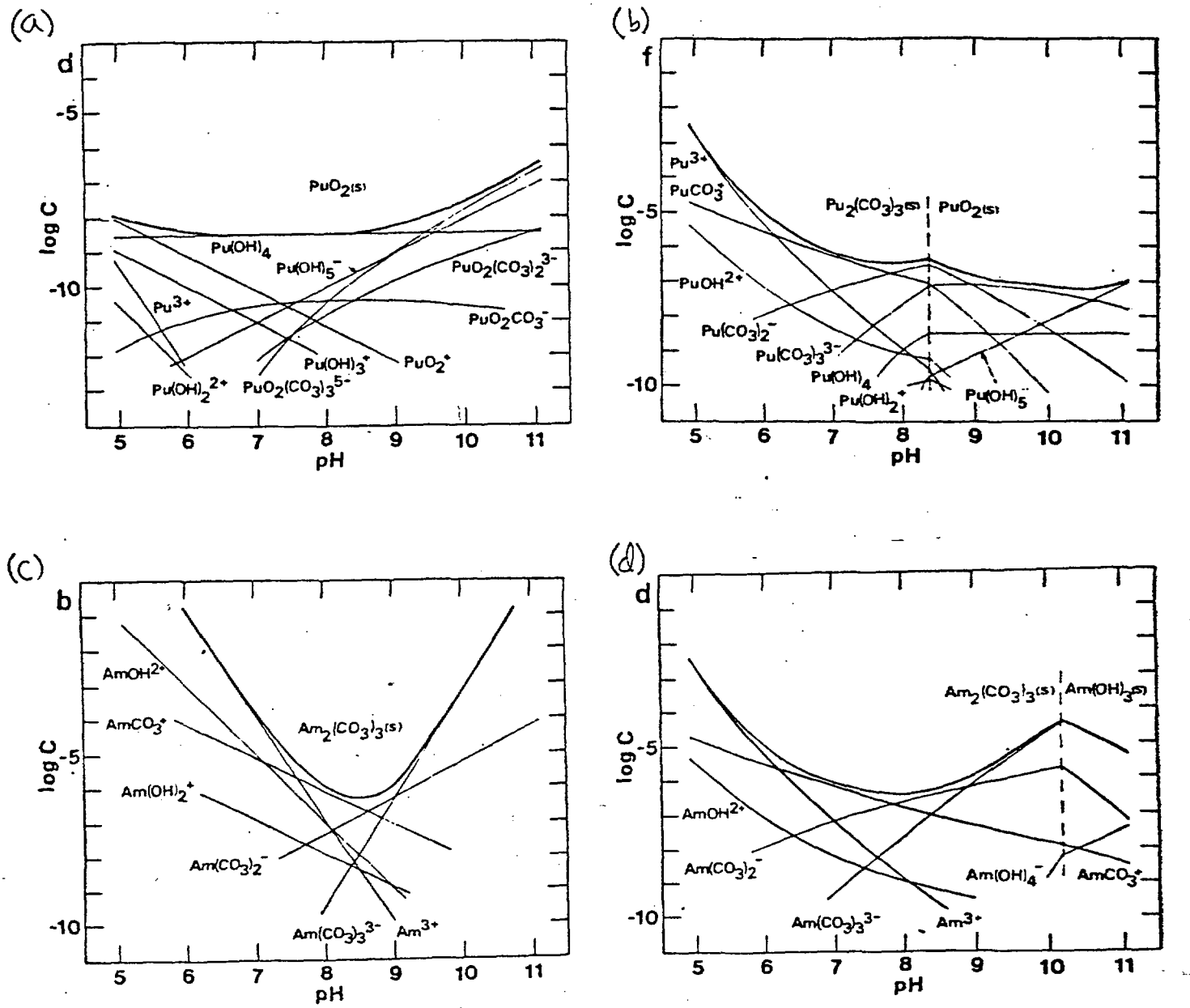

Figure 3. Plutonium solubilities (M) and species in solution $\Sigma\ CO_3 = 7.9 \times 10^{-3}$ M;
Eh = 0.8 - 0.06 pH (figure a);
Eh = 0.2 - 0.06 pH (figure b).

Americium solubilities (M) and species in solution $P(CO_2) = 10^{-3.5}$ atm (figure c) and
$\Sigma\ CO_3 = 7.9 \times 10^{-3}$ M (figure d);
Eh = 0.08 - 0.06 pH and Eh = 0.2 - 0.06 pH.

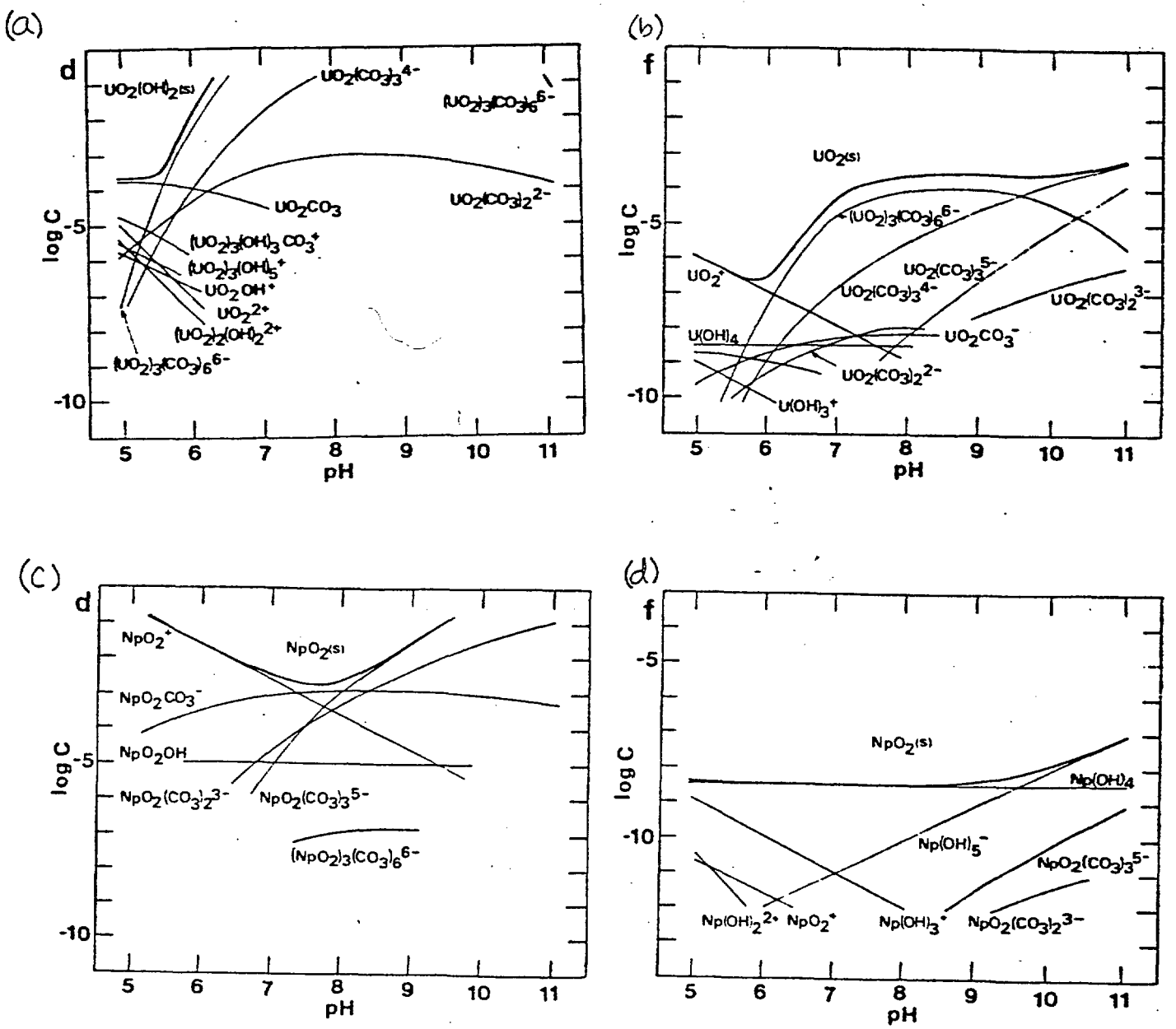

Figure 2. Uranium solubilities (M) and species in solution $\Sigma\ CO_3 = 7.9 \times 10^{-3}$ M;
Eh = 0.8 - 0.06 pH (figure a);
Eh = 0.2 - 0.06 pH (figure b).

Neptunium solubilities (M) and species in solution $\Sigma\ CO_3 = 7.9 \times 10^{-3}$ M;
Eh = 0.8 - 0.06 pH (figure c);
Eh = 0.2 - 0.06 pH (figure d).

TABLE 3. Comparison of 10 CFR Part 20 and ICRP 30 MPCs

Element	Isotope	μCi/ml 10 CFR 20(2)	μCi/ml ICRP-30(3)
Am	Am^{241}	4×10^{-6}	1.7×10^{-7}
	Am^{243}	4×10^{-6}	1.7×10^{-7}
Pu	Pu^{239}	5×10^{-6}	6.7×10^{-7}
	Pu^{240}	5×10^{-6}	6.7×10^{-7}
	Pu^{242}	5×10^{-6}	1.0×10^{-6}
Np	Np^{237}	3×10^{-6}	1×10^{-8}
U	U^{234}	4×10^{-5}	$1.4. \times 10^{-6}$
	U^{236}	3×10^{-5}	1.7×10^{-6}
	U^{238}	3×10^{-5}	1.7×10^{-6}

1. *Calculated assuming an average daily water intake of 2200 cm^3 (ICRP II) and a factor of 10 for non-occupational exposures.

2. Code of Federal Regulations Chapter 10, Part 20, Appendix B, Revised January 1982.

3. Limits for Intakes of Radionuclides by Workers, ICRP Publication 30, Pergamon Press, New York, 1978.

Table 4. Projected Total Inventory of High-Activity Constituents of Spent Fuel in the United States[a] (after Wood and Rai, 1981)

Nuclide	Initial Inventory (Ci)	Inventory at 1000 yr (Ci)[b]	Ci/Mole	Mole Fraction	MPC[c] Moles/Liter
^{234}U	7×10^{3}	7.4×10^{4}	1.4	.001	4.8×10^{-10}
^{236}U	1×10^{4}	3×10^{4}	1.4×10^{-2}	.006	4.8×10^{-8}
^{238}U	3×10^{4}	3×10^{4}	8×10^{-5}	.994	8.4×10^{-6}
^{237}Np	3×10^{4}	1×10^{5}	0.2		2.4×10^{-11}
^{239}Pu	2.8×10^{7}	2.7×10^{7}	15	.68	3.1×10^{-11}
^{240}Pu	4.2×10^{7}	3.8×10^{7}	54	.26	8.7×10^{-12}
^{242}Pu	1.5×10^{5}	1.5×10^{5}	0.9	.06	5.2×10^{-10}
^{241}Am	1.5×10^{8}	7.8×10^{7}	780	.79	8.6×10^{-14}
^{243}Am	1.3×10^{6}	1.2×10^{6}	45	.21	1.5×10^{-12}

[a]Based on 93,000 metric tons of heavy metal, the estimated 10-year-old spent fuel inventory in the year 2010.

[b]Change in inventory due to radioactive decay.

[c]MPC calculated from ICRP 30 assuming 2200 cm^3 average daily water intake and a factor of 10 for nonoccupational exposures.

Table 5. Allard Solubilities/MPC (ICRP 30)

	Solubility/MPC	Ratio
U^{238}ox	$10^{0}/8.4 \times 10^{-6}$	1.2×10^{5}
U^{236}ox	$6 \times 10^{-3}/4.8 \times 10^{-8}$	1.3×10^{5}
U^{234}ox	$1.4 \times 10^{-4}/4.8 \times 10^{-10}$	2.9×10^{5}
U^{238}red	$3 \times 10^{-3}/8.4 \times 10^{-6}$	3.6×10^{2}
U^{236}red	$1.8 \times 10^{-4}/4.8 \times 10^{-8}$	3.8×10^{3}
U^{234}red	$2 \times 10^{-8}/4.8 \times 10^{-10}$	4×10^{2}
Np^{237}ox	$10^{-1}/2.4 \times 10^{-11}$	4.2×10^{9}
Np^{237}red	$10^{-8}/2.4 \times 10^{-11}$	4.2×10^{2}
Am^{241}both	$7.9 \times 10^{-6}/8.6 \times 10^{-14}$	9.2×10^{7}
Am^{243}both	$2.1 \times 10^{-6}/1.5 \times 10^{-12}$	1.4×10^{6}
Pu^{239}ox	$6.8 \times 10^{-9}/3.1 \times 10^{-11}$	2.2×10^{2}
Pu^{240}ox	$2.6 \times 10^{-9}/8.7 \times 10^{-12}$	3×10^{2}
Pu^{242}ox	$0.6 \times 10^{-9}/5.2 \times 10^{-10}$	1.2×10^{0}
Pu^{239}red	$6.8 \times 10^{-8}/3.1 \times 10^{-11}$	2.2×10^{3}
Pu^{240}red	$2.6 \times 10^{-8}/8.7 \times 10^{-12}$	3×10^{3}
Pu^{242}red	$0.6 \times 10^{-8}/5.2 \times 10^{-10}$	1.2×10^{1}

TABLE 6. Comparison of BWIP SCR and Allard Radionuclide Solubility/MPC

I Nuclide	II Eh	III BWIP SCR (MPC from 10 CFR 20)	IV Allard (MPC from ICRP 30)	Disagreement Column IV/ Column III
^{241}Am	both ox, red	10^{-6}	10^{8}	10^{14}
^{243}Am	both ox, red	10^{-4}	10^{6}	10^{10}
^{242}Pu	ox	10^{-5}	10^{0}	10^{5}
^{242}Pu	red		10^{1}	10^{6}
^{240}Pu	ox	10^{-3}	10^{2}	10^{5}
^{240}Pu	red		10^{3}	10^{6}
^{239}Pu	ox	10^{-3}	10^{2}	10^{3}
^{239}Pu	red	10^{-1}	10^{3}	10^{4}
^{237}Np	ox	10^{1}	10^{9}	10^{8}
^{237}Np	red	10^{-11}	10^{2}	10^{13}
^{234}U	ox	10^{-1}	10^{5}	10^{6}
^{234}U	red	10^{-4}	10^{2}	10^{6}
^{236}U	ox	10^{-1}	10^{5}	10^{6}
^{236}U	red	10^{-4}	10^{3}	10^{7}
^{238}U	ox	10^{-1}	10^{5}	10^{6}
^{238}U	red	10^{-4}	10^{2}	10^{6}

TABLE 8 Thermodynamic Data

I. Am^{3+} (25°C, $\mu = 0$)

Precipitates	Log K
$Am(OH)_3(S) + 3H^+ = Am^{3+}\ 3H_2O$	15.9 (1)
Hydrolysis	
$Am^{3+} + H_2O = Am(OH)^{2+} + H^+$	-7.7 (2)*
$Am^{3+} + 2H_2O = Am(OH)^{2+} + 2H^+$	-16.0 (1)
$Am^{3+} + 3H_2O = Am(OH)_3^0 + 3H^+$	-24.3 (1)
Complexes	
$Am^{3+} + CO_3^{2-} = AmCO_3^+$	7.5 (3)
$Am^{3+} + 2CO_3^{2-} = Am(CO_3)_2^-$	12.0 (3)
$Am^{3+} + F^- = AmF^{2+}$	4.5 (4)
$Am^{3+} + 2F^- = AmF_2^+$	7.4 (4)
$Am^{3+} + 3F^- = AmF_3^0$	10.6 (4)
$Am^{3+} + SO_4^{2-} = AmSO_4^+$	3.9 (4)
$Am^{3+} + 2SO_4^{2-} = Am(SO_4)_2^-$	5.4 (4)
$Am^{3+} + Cl^- = Am\ Cl_2^+$	1.12 (4)
$Am^{3+} + 2Cl^- = Am\ Cl_2^+$	0.97 (4)*

II. Pu

Precipitates	Log K
$PuO_2(s) + 4H^+ = Pu^{4+} + 2H_2O$	-7.0 (5)
$Pu(OH)_3(s) + 3H^+ = Pu^{3+} = 3H_2O$	22 (5)
$PuO_2(OH)(s)H^+ = PuO_2^+ + H_2O$	5 (5)
$PuO_2(OH)_2(s) + 2H^+ = PuO_2^{2+} + 2H_2O$	3 (5)

* values for Cm^{3+}

TABLE 8 (Continued)

$PuF_4(s) = Pu^{4+} + 4F^-$	-13	(5)
$PuF_3(s) = Pu^{3+} + 3F^-$	-10	(5)
Complexes		
$PuO_2^{2+} + H_2O = PuO_2OH^+ + H^+$	-5.6	(4)
$PuO_2^{2+} + 2H_2O = PuO_2(OH)_2^\circ + 2H^+$	-10.4	(4)
$PuO^{2+} + 3H_2O = PuO_2(OH)_3^- + 3H^+$	-20	(4)
$2PuO_2^{2+} + 2H_2O = (PuO_2)_2(OH)_2^{2+} + 2H^+$	-8.4	(4)
$3PuO_2^{2+} + 4H_2O + (PuO_2)_3(OH)_4^{2+} + 4H^+$	-15	(4)
$3PuO_2^{2+} + 5H_2O = (PuO_2)_3(OH)_5^+ + 5H^+$	-21.7	(4)
$PuO_2^{2+} + F^- = PuO_2F^+$	5.6	(4)
$PuO_2^{2+} + 2F^- = PuO_2F_2^\circ$	10.6	(4)
	Log K	
$PuO_2^{2+} + 3F^- = PuO_2F_3^-$	15.9	(4)
$PuO_2^{2+} + 4F^- = PuO_2F_4^{2-}$	18.8	(4)
$PuO_2^{2+} + SO_4^{2-} = PuO_2SO_4^\circ$	3	(4)
$PuO_2^{2+} + 2CO_3^{2-} = PuO_2(CO_3)_2^{2-}$	15	(4)
$PuO_2^{2+} + Cl^- = PuO_2Cl^+$	-0.3	(4)
$PuO_2^+ + H_2O = PuO_2(OH)^\circ$	-9.7	(4)
$PuO_2^+ + 2H_2O = PuO_2(OH)^-$	-19	(4)
$PuO_2^+ + Cl^- = PuO_2Cl^\circ$	-.17	(4)
$Pu^{4+} + H_2O = Pu(OH)_3^+ + H^+$	-0.5	(4)
$Pu^{4+} + H_2O = Pu(OH)_2^{2+} + 2H^+$	-2.3	(4)
$Pu^{4+} + 3H_2O = Pu(OH)_3^+ + 3H^+$	-5.3	(4)
$Pu^{4+} + 4H_2O = Pu(OH)_4^\circ + 4H^+$	-9.5	(4)
$Pu^{4+} + 5H_2O = Pu(OH)_5^- + 5H^+$	-15	(4)
$Pu^{4+} + F^- = PuF^{3+}$	8	(5)

TABLE 8 (Continued)

$Pu^{4+} + Cl^- = PuCl^{3+}$	0.9	(5)
$Pu^{4+} + SO_4^{2-} = PuSO_4^{2+}$	5.7	(4)
	Log K	
$Pu^{4+} + 2SO_4^{2-} = Pu(SO4)_2^{\circ}$	10.2	(4)
$Pu^{4+} + CO_3^{2-} = PuCO_3^{2+}$	41	(4)
$Pu^{3+} + H_2O = Pu(OH)^{2+} + H^+$	-6.8	(4)
$Pu^{3+} + 2H_2O = Pu(OH)_2^{+} + 2H^+$	-15.9	(4)
$Pu^{3+} + 3H_2O = Pu(OH)_3^{\circ} + 3H^+$	-25.3	(4)
$Pu^{3+} + 4H_2O = Pu(OH)_4 + 4H^+$	-35.8	(4)
$Pu^{3+} + SO_4^{2-} = PuSO_4^{+}$	3.5	(5)
$Pu^{3+} + Cl^- = PuCl^{2+}$	-0.1	(4)

Redox Reactions	std. pot (E°)	Log K	
$PuO_2^{2+} + e^- = PuO_2^{+}$	1.02v	17.2	(6)
$PuO_2^{2+} + 4H^+ + 2e^- = Pu^{4+} + 2H_2O$	1.03v	34.8	(6)
$PuO2^{2+} + 4H^+ + 3e^- = Pu^{3+} + 2H_2O$	1.02v	51.7	(6)

III. Np

Precipitates

$NpO_2(s) + 4H^+ = Np^{4+} + 2H^2O$	-4	(7)
$NpO_2(OH)(s) + H^+ = NpO_2^{+} + H_2O$	4.7	(7)
$NpO_2(OH)_2\ (s) + 2H_2O = NpO_2^{2+} + 2H_2O$	6.6	(7)

Complexes	Log K	
$Np^{4+} + H_2O = Np(OH)^{3+} + H^+$	-1.49	(4)
$Np^{4+} + 2H_2O = Np(OH)_2^{2+} + 2H^+$	-2.8	(4)
$Np^{4+} + 3H_2O = Np(OH)_3^{+} + 3H^+$	-5.6	(4)
$Np^{4+} + 4H_2O = Np(OH)_4^{\circ} + 4H^+$	-9.9	(4)
$Np^{4+} + 5H_2O = Np(OH)_5^{-} + 5H^+$	-17	(4)

TABLE 8 (Continued)

$Np^{4+} + Cl^- = NpCl^{3+}$	1.2	(4)
$Np^{4+} + 2Cl^- = NpCl_2^{2+}$	1.9	(4)
$Np^{4+} + 3Cl^- = NpCl_3^{+}$	2.3	(4)
$Np^{4+} + F^- = NpF^{3+}$	8.3	(4)
$Np^{4+} + 2F^- = NpF_2^{2+}$	14.5	(4)
$Np^{4+} + 3F^- = NpF_3^{+}$	20.3	(4)
$Np^{4+} + 4F^- = NpF_4^{\circ}$	25.1	(4)
$Np^{4+} + SO_4^{2-} = Np\ (SO_4)^{2+}$	5.5	(4)
$Np^{4+} + 2SO_4^{2-} = Np\ (SO_4)^{\circ}$	8.5	(4)
$Np^{4+} + CO_3^{2-} = Np\ CO_3^{\ 2+}$	41	(4)*
$NpO_2^{+} + Cl^- = NpO_2Cl$	-0.1	(4)
$NpO_2^{+} + H_2O = NpO_2OH + H^+$	-8.85	(4)
$NpO_2^{+} + 2H_2O = NpO_2(OH)_2^{-} + 2H^+$	-18	(4)
$NpO_2^{+} + CO_3^{2-} = NpO_2(CO_3)^-$	5.9	(8)
$NpO_2^{+} + 3\ CO_3^{2-} = NpO_2(CO_3)_3^{5-}$	16.3	(8)
$NpO_2^{+} + H_2O = NpO_2OH^+ + H^+$	-5.15	(4)
$NpO_2^{2+} + 2H_2O = NpO_2(OH)_2^{\circ} + 2H^+$	-10.2	(4)
$NpO_2^{2+} + 3H_2O = NpO_2(OH)_3^- + 3H^+$	-19	(4)
$2NpO_2^{2+} + 2H_2O = (NpO_2)_2(OH)_2^{2+} + 2H^+$	-6.39	(4)
$3NpO_2^{2+} + 4H_2O = (NpO_2)_3(OH)_4^{2+} + 4H^+$	-13	(4)
$3NpO_2^{2+} + 5H_2O = (NpO_2)_3(OH)_5^+ + 5H^+$	-17.5	(4)
$NpO_2^{2+} + F^- = NpO_2\ F^+$	4.6	(4)
$NpO_2^{2+} + 2F^- = NpO_2\ F_2^{\circ}$	7.7	(4)
$NpO_2^{2+} + SO_4^{2-} = NpO_2\ SO_4^{\circ}$	3.27	(4)

*Based on value for $PuCO_3^{2+}$

TABLE 8 (Continued)

$NpO_2^{2+} + 2SO_4^{2-} = NpO_2(SO_4)_2^{2-}$	3.8	(4)
$NpO_2^{2+} + Cl^- = NpO_2Cl^+$	0.3	(4)

Redox Reactions

$NpO_2^{2+} + e^- = NpO_2^+$	E^o= 1.24v log K = 20.9	(9)
$NpO_2^{2+} + 4H^+ + 2e^- = Np^{4+} + 2H_2O$	E^o= 0.99v log K = 33.5	(9)

IV. U

Precipitates

	Log K	
$UO_2(s) + 4H^+ = U^{4+} + 2H_2O$	-4.6	(5)
$UO_2(OH)_2(s) + 2H^+ = UO_2^{2+} + 2H_2O$	+5.4	(5)
$UO_2CO_3\ (s) = UO_2^{2+} + CO_3^{2-}$	-14.5	(5)
$UF_4(s) = U^{4+} + 4F^-$	-24.0	(5)

Complexes

$U^{4+} + H_2O = U(OH)^{3+} + H^+$	-0.65	(4)
$U^{4+} + 2H_2O = U(OH)_2^{2+} + 2H^+$	-2.6	(4)
$U^{4+} + 3H_2O = U(OH)_3^+ + 3H^+$	-5.8	(4)
$U^{4+} + 4H_2O = U(OH)_4^o + 4H^+$	-10.3	(4)
$U^{4+} + 5H_2O = U(OH)_5^{-1} + 5H^+$	-16.0	(4)
$U^{4+} + F^- = UF^{3+}$	8.77	(4)
$U^{4+} + 2F^- = UF_2^{2+}$	14.7	(4)
$U^{4+} + 3F^- = UF_3^+$	19.4	(4)
$U^{4+} + 4F^- = UF_4^o$	24.1	(4)
$U^{4+} + 5F^- = UF_5^-$	25.9	(4)
$U^{4+} + 6F^- = UF_6^{2-}$	28.4	(4)
$U^{4+} + SO_4^{2-} = USO_4^{2+}$	5.5	(4)
$U^{4+} + SO_4^{2-} = U(SO_4)_2^o$	9.8	(4)

TABLE 8 (Continued)

$U^{4+} + Cl^- = UCl^{3+}$	1.5	(4)
$U^{4+} + CO_3^{2-} = UCO_3^{2+}$	41	(4)
$UO_2^{2+} + H_2O = UO_2OH^+ + H^+$	-5.5	(10)
$UO_2^{2+} + 2H_2O = UO_2(OH)_2^\circ + 2H^+$	-11.9	(10)
$2\ UO_2^{2+} + 2H_2O = (UO_2)_2(OH)_2^{2+} + 2H^+$	-5.89	(10)
$3\ UO_2^{2+} + 5H_2O = (UO_2)_3(OH)_5^+ + 5H^+$	-16.5	(10)
$3\ UO_2^{2+} + 4H_2O = (UO_2)_3(OH)_4^{2+} + 4H^+$	-12.3	(10)
$3\ UO_2^{2+} + 7H_2O = (UO_2)_3(OH)_7^- + 7H^+$	-22.8	(10)
$4\ UO_2^{2+} + 7H_2O = (UO_2)_4(OH)_7^+ + 7H^+$	-30.8	(10)
$UO_2^{2+} + CO_3^{2-} = UO_2CO_3^\circ$	7.50	(4)
$UO_2^{2+} + 2CO_3^{2-} = UO_2(CO_3)_2^{2-}$	16.7	(4)
$UO_2^{2+} + 3CO_3^{2-} = UO_2(CO_3)_3^{4-}$	20.9	(4)
$UO_2^{2+} + SO_4^{2-} = UO_2\ SO_4^\circ$	2.95	(4)
$UO_2^{2+} + 2SO_4^{2-} = UO_2(SO_4)_2^{2-}$	4.28	(4)
$UO_2^{2+} + 3SO_4^{2-} = UO_2(SO_4)_3^{4-}$	4.70	(4)
$UO_2^{2+} + Cl^- = UO_2Cl^+$	0.21	(4)
$UO_2^{2+} + F^- = UO_2F^+$	5.16	(4)
$UO_2^{2+} + 2F^- = UO_2\ F_2^\circ$	8.85	(4)
$UO_2^{2+} + 3F^- = UO_2\ F_3^-$	11.42	(4)
$UO_2^{2+} + 4F^- = UO_2\ F_4^{2-}$	11.97	(4)

Redox Reactions

$UO_2^{2+} + e^- = UO_2^+$	$E^\circ = .163v.$	$\log K = 2.75$ (6)
$UO_2^{2+} + 4H^+ + 2e^- = U^{4+} + 2H_2O$	$E^\circ = .273v.$	$\log K = 9.22$(6)

*Based on value for $PuCO_3^{2+}$

References to Table 8

(1) Silva, R. J., 1982, "Solubilities of crystalline Nd and Am Trihydroxides," ONWI Topical Report, LBL-15055.

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