

A Thermodynamic Reference Database for Nuclear Waste Disposal

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The Project

- Design of waste repositories requires reliable thermodynamic data to predict the geochemical behaviour of contaminants
- Need: aqueous speciation, solubility limiting solid phases and ion-interaction parameters
- Challenges: Incomplete sets of major and trace elements, inconsistencies between species considered and corresponding formation constants / activity models, restricted variation ranges of parameters (temperature, density, pressure, ionic strength)
- Action: Launch of THEREDA in 2006

The Partners and Goal

- Gesellschaft für Anlagen- und Reaktorsicherheit mbH, Braunschweig (Coordinator)
- Helmholtz-Zentrum Dresden-Rossendorf, Institute of Resource Ecology
- Karlsruhe Institute of Technology, Institute for Nuclear Waste Disposal
- TU Bergakademie Freiberg, Institute of Inorganic Chemistry
- AF-Consult Switzerland AG, Baden (Switzerland).

Main objective: a centrally administrated and maintained database of verified thermodynamic parameters for environmental applications in general and radiochemical issues in particular

The Chemistry

- Actinides, Fission and Activation Products:
 - ◆ Pa, Th, U, Np, Pu, Am, Cm
 - ◆ Rb, Sr, Tc, Cs, Sm, Nd, Ba, Ra
- Matrix:
 - ◆ System of oceanic salts: Na⁺, K⁺, H⁺, OH⁻, Mg²⁺, Ca²⁺, Cl⁻, SO₄²⁻, CO₃²⁻ / HCO₃⁻ / CO₂(aq) – H₂O containing the elements H, O, Na, K, Mg, Ca, Cl, S, C
 - ◆ Hydrated cement phases (including Al, Si)
- Ion-Ion-Interactions:
 - ◆ Pitzer approach
 - ◆ Planned: SIT & extended Debye-Hückel

Releases / Extended Interface

- Eight new official releases since launching the initial database, all consistent with Pitzer (in bold: additions to the hexary system of oceanic salts)
 - ◆ Na, Mg, Ca – Cl – **Am(III), Nd(III), Cm(III)** – H₂O(l) (2011-12-23)
 - ◆ Na, K, Mg, Ca – Cl, SO₄ – **HCO₃/CO₂(g)** – H₂O(l) (2012-02-21)
 - ◆ Na – Cl – **Np(V)** – H₂O(l) (2012-11-30)
 - ◆ Na, Mg, Ca, K – Cl, SO₄ – **HCO₃/CO₂(g)** – **Cs** – H₂O(l) (2013-01-28)
 - ◆ Na, K, Mg, Ca – Cl, SO₄ – **HCO₃/CO₂(g)** – **Si, Al** – H₂O(l) (2013-07-04)
 - ◆ Na, K, Ca – Cl – **HCO₃/CO₂(g)** – **Th(IV), Np(IV), Pu(IV)** – H₂O(l) (2013-08-04)
 - ◆ Na, Mg, Ca – Cl, SO₄, **HCO₃ – Am(III), Cm(III)** – H₂O(l) (2013-10-21)
 - ◆ Na, Mg, Ca, K – Cl, SO₄, CO₃, HCO₃, Si – **U(IV/VI)** – H₂O(l) (2014-07-14).
- Download as separate files (www.thereda.de → navigation menu: THEREDA Data Query → Tailored Databases) in five formats: generic JSON type and specific to geochemical speciation codes (PHREEQC, EQ3/6, ChemApp, Geochemist's Workbench – GWB).
- Access to data records is now also possible through interactive forms (menu: THEREDA Data Query → Single Data Query // Complex Systems), both with export options as CSV or MS Excel file.
- New interactive web-based tool for data entry and editing – though only visible to members of the editorial board of THEREDA.
- Eight issued technical papers (Downloads → Documentations) add transparency and promote the transition of THEREDA into an open information and discussion platform – covering the database itself as well as geochemical modeling at large.

Quality Assurance (QA)

- Major milestones in QA:
 - ◆ Monitor data selections,
 - ◆ Automatic logging of all data changes,
 - ◆ Extension of the internal calculation scheme for mutually dependent thermodynamic data to check for data consistency and plausibility.
- An illustration of THEREDA's capability: the solubility of freshly precipitated U(OH)₄(am) in 1 m solutions of NaCl (Fig. 1) and NaHCO₃ (Fig. 2) compared to predictions (based on two databases from the Yucca Mountain Project – data0.ypf.R1/2) and experiments.
- Deviations due to differences in aqueous speciation and Pitzer data (Fig. 1) as well as no data for carbonates (U(CO₃)_n⁴⁻²ⁿ) (Fig. 2).

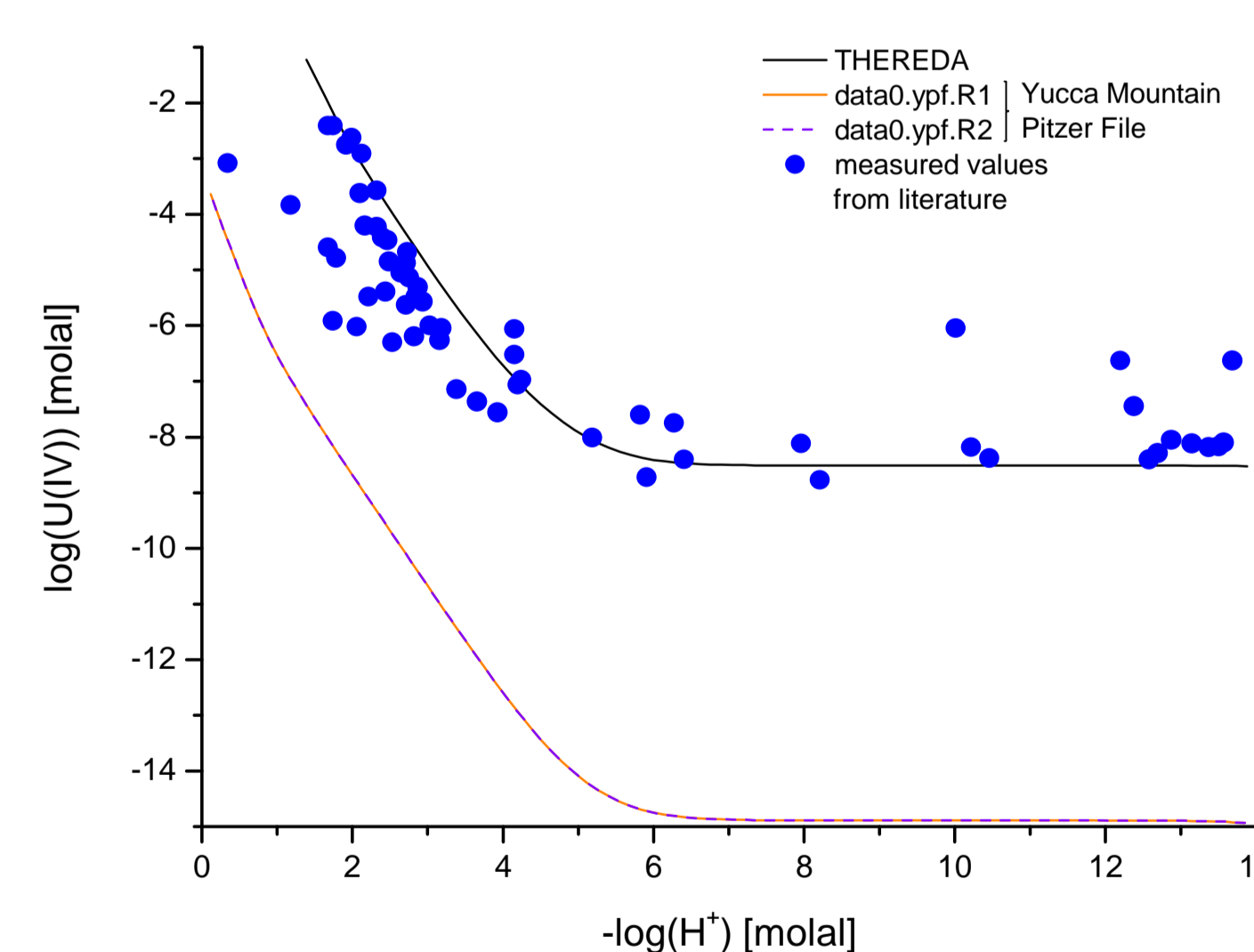


Fig. 1: Solubility of U(OH)₄(am) in 1 m NaCl solution (lines: database predictions, symbols: experimental data from Jove-Colon, C. et al. (2007): Report ANL-EBS-MD-000045 REV 03, SNL, Las Vegas).

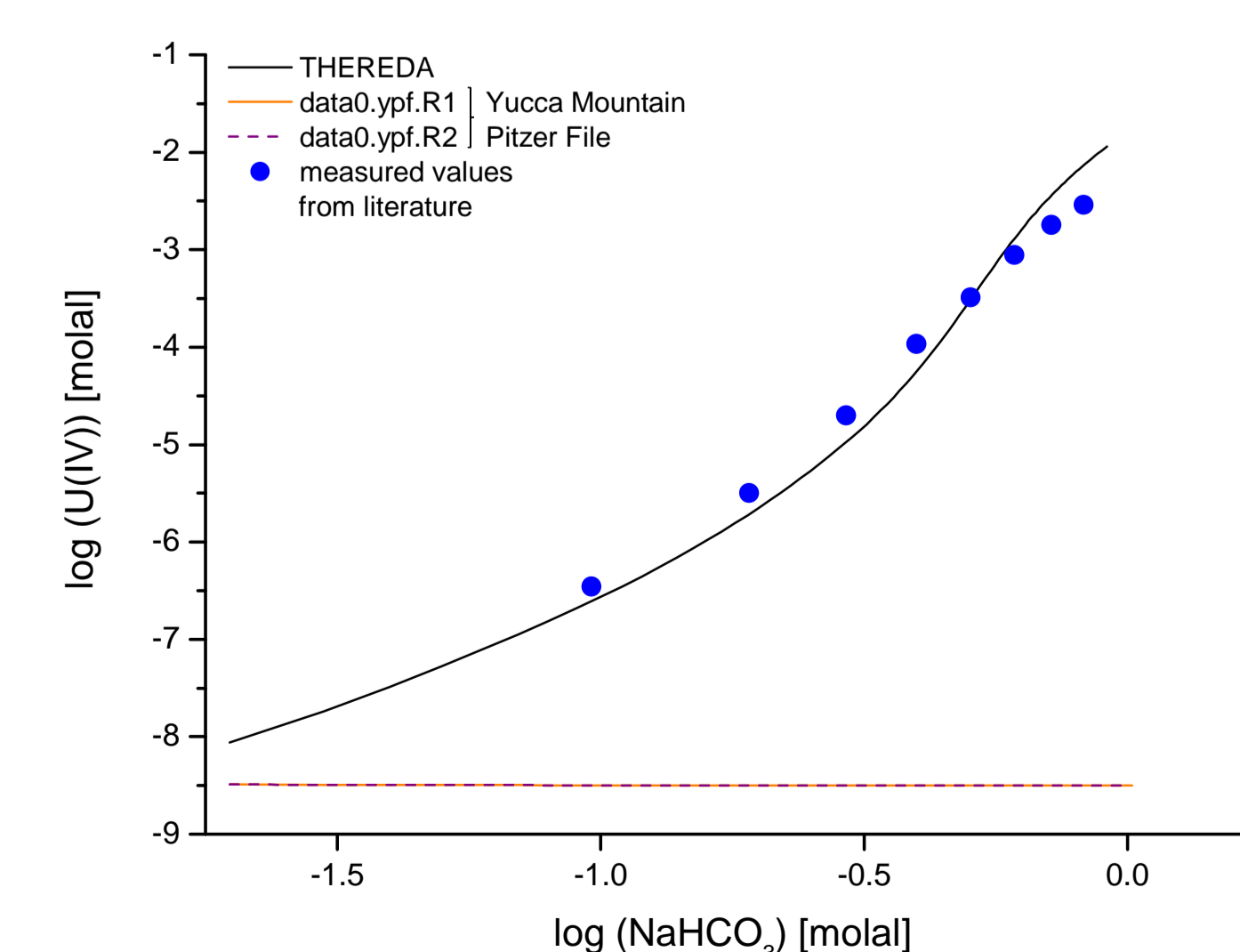


Fig. 2: Solubility of U(OH)₄(am) in 1 m NaHCO₃ solution (experimental data from Rai, D. et al. Mat. Res. Soc. Symp. Proc., 35, (1995), 1143).

Surface Complexation

- A complete treatment of geochemical processes must include sorption phenomena.
- Thermodynamically consistent treatment: only possible with surface complexation modeling (SCM).
- Support for models implemented in GWB and PHREEQC: Diffuse Double Layer Model (DDL), Constant Capacitance Model (CC), Non-electrostatic Model (NE), 1pK-Basic Stern Model (1pK-BS).
- Stored for each mineral: specific surface area, surface binding site density, surface protolysis constants (pK). Capacitance values will be kept for the CC and the 1pK-BS model. Surface complex formations constants (logK) are entered for given combinations of mineral, ligand, and model.
- Severe general SCM problems: speculative species, unreliable, contradicting or missing thermodynamic parameters.
- Currently SCM data are stored for 298.15 K only, but adaptation to temperature-dependent functions is possible.
- Extension towards SCM highlighted the flexibility of the current THEREDA database design.

■ **We are looking forward to receiving feedback on THEREDA and are hoping for intensified interactions of the THEREDA database project at www.thereda.de with the international user community.**

Acknowledgements

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