# *Potential New Ligand Systems for Binding Uranyl Ions in Seawater Environments*

## Fuel Cycle Research & Development

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# APPENDIX E

# FCT DOCUMENT COVER SHEET [1]

| | |
|---|---|
| Name/Title of Deliverable/Milestone/Revision No. | Potential New Ligand Systems for Binding Uranyl Ions in Seawater Environments |
| Work Package Title and Number | Fuel Resources - LBNL FT-15LB031003 |
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| Quality Rigor Level for Deliverable/Milestone[2] | ☐ QRL-3 | ☐ QRL-2 | ☐ QRL-1<br>☐ Nuclear Data | ☒ Lab/Participant QA Program (no additional FCT QA requirements) |

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QA program which meets the requirements of
☒ DOE Order 414.1 ☐ NQA-1-2000 ☐ Other

**This Deliverable was subjected to:**

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# SUMMARY

Work began this quarter on a new project involving a combined computational and biosynthetic approach to selective recognition of uranyl ion in aqueous solution. This project exploits the results of computational studies to discover new ligand classes. Synthetic studies will follow to generate target systems for uranyl binding and determination of binding constants. The process will be iterative, with results from computation informing synthesis, and vice versa. The theme of the ligand classes to be examined initially will be biologically based. New phosphonate-containing α-amino acid N-carboxyanhydride (NCA) monomers were used recently to prepare well-defined phosphonate-containing poly-peptides and block copolypeptides. Our first approach is to utilize these phosphate- and phosphonate-containing NCAs for the coordination of uranyl. The work includes the laboratory-scale preparation of a series of NCAs and the full thermodynamic and spectroscopic characterization of the resulting uranyl complexes. We are also evaluating the sequestering activity in different physiological and environmental conditions of these copolymers as well as their biodegradability.

# 1. INTRODUCTION

Uranium is the second most naturally occurring actinide (after thorium) but is the most commonly used in nuclear applications such as fuel in fission reactors (in the form of enriched uranium, $^{235}U$) and military munitions (depleted uranium, $^{238}U$, 99.3% of natural abundance). Though uranium is a common trace element and some intake and accumulation in living organisms is natural, both α-emitters $^{235}U$ and $^{238}U$ can induce radiation damage and carcinogenesis as well as chemical damage in kidneys and liver. Among the four oxidation states of uranium (III, IV, V, VI), uranyl ion ($UO_2^{2+}$, U(VI)) is the most stable form in aqueous solutions and in vivo, and uranyl compounds have therefore being the focus of most pharmacology studies. In humans nearly all of the long-retained uranium in the body remains in the bones.

This research explores new synthetic platforms for the selective coordination of uranyl inspired from existing actinide decorporation ligands developed at LBNL as well as from the high affinity displayed by bone matrices for this ion.

A first approach will include the preparation of libraries of ligands generated through high-throughput synthesis and screened for the greatest uranyl affinity. The bidentate catecholamide (CAM), terephthalamide (TAM) and hydroxypyridinone (HOPO) moieties are known to form highly stable complexes with transition metals, lanthanides and actinides. These functional groups will be incorporated along with carboxylic acids and polyol groups into peptoid backbones with multiple variable positions. Following peptoid synthesis, each resin sample will be analyzed for its uranyl affinity and sequestration potential through spectrofluorimetric and colorimetric microtiter plate arrays based on the high luminescence sensitization properties of the metal-binding units.

In addition, synthetic polypeptide mimics of phospho-proteins have been studied for many years; yet have been limited by inefficient synthesis and the inability to be incorporated into well-defined block copolymers. A second approach of the project will focus on inserting phosphate and phosphonate groups in known actinide ligands that contain hydroxypyridinone metal-binding units and display high affinity for uranyl. The tailored structure will be studied for their increased sequestration capability for uranyl as well as their potential for uranyl detection trough activation of luminescence upon uranyl binding.

Once the laboratory-scale preparation of a series of selected new ligands completed, the full thermodynamic and spectroscopic characterization of the resulting uranyl complexes will be performed. We will also evaluate the sequestering activity in different physiological and environmental conditions of these platforms as well as their biodegradability.

We anticipate that this fundamental science will find use beyond actinide separation technologies in areas such as nuclear waste remediation and nuclear materials.

# 2. RESULTS

We are exploring new synthetic platforms for the selective coordination of uranyl inspired from the high affinity displayed by bone matrices for this ion. Synthetic polypeptide mimics of phospho-proteins have been studied for many years; yet have been limited by inefficient synthesis and the inability to be incorporated into well-defined block copolymers. New

phosphonate-containing α -amino acid N-carboxyanhydride (NCA) monomers were used recently to prepare well-defined phosphonate-containing poly-peptides and block copolypeptides. Our first approach is to utilize these phosphate- and phosphonate-containing NCAs for the coordination of uranyl. The work includes the laboratory-scale preparation of a series of NCAs and the full thermodynamic and spectroscopic characterization of the resulting uranyl complexes. We are also evaluating the sequestering activity in different physiological and environmental conditions of these copolymers as well as their biodegradability.

A parallel approach will be taken by inserting phosphate and phosphonate groups in known actinide ligands that contain hydroxypyridinone metal-binding units and display high affinity for uranyl. The tailored structure will be studied for their increased sequestration capability for uranyl as well as their potential for uranyl detection trough activation of luminescence upon uranyl binding.

One postdoctoral researcher, Dr. Ilya Yakovlev, was hired at LBNL on December 1, 2014. Dr. Yakovlev is a synthetic organic chemist with a strong background in the preparation of new biodegradable α-amino acid N-carboxyanhydride (NCA) monomers as well-defined phosphate- and phosphonate-containing poly-peptides and block copolypeptides. In addition, he has some previous experience in the preparation of macrocyclic ligands for the selective binding of radioactive transition metals. His background makes him a perfect candidate to explore the synthesis of new ligand platforms for binding uranyl. Finally, the laboratory has extensive expertise in the evaluation of solution thermodynamic parameters for metal complexation using spectroscopic methods (fluorescence, UV-visible, mass spectrometry) and in the handling of actinides in biological systems.

The second quarter of fiscal year 2015 will be dedicated to the synthesis of bidentate metal-binding units as precursors for the multidentate uranyl-binding platforms. Dr. Yakovlev has spent the month of December 2014 setting up the laboratory and purchasing chemicals and reagents necessary for these syntheses. The preparation of peptoid libraries will then be initiated by the end of the quarter using up to 4 different metal-binding units.

The third quarter of fiscal year 2015 will be spent on the development of peptoid libraries and on reliable screening methods for uranyl selectivity. We anticipate that by the end of the third quarter, the screens will provide a selection of promising structures with high uranyl-affinity.

The fourth quarter of fiscal year 2015 will focus on the larger-scale preparation, and solution thermodynamic and spectroscopic characterizations of selected structures that exhibit the highest affinity for uranyl. Additional work will then be done on the addition of phosphate and phosphonate binding groups within the platforms to enhance uranyl binding without altering the luminescence properties necessary for high-throughput screening.

## 3. ACKNOWLEDGMENTS

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