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Technical Progress Report
Private Sector Initiative Between the United States and Japan

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ACRONYMS

CRIEPI	Central Research Institute of Electric Power Industry (Japan
DOE	Department Of Energy
FY	fiscal year
HLW	high level waste
JAPC	Japan Atomic Power Company
KHI	Kawasaki Heavy Industries
LMR	liquid metal reactors
MSO	molten salt oxidation
MURR	Missouri University Research Reactor
P/T	partitioning/transmutation
PWR	pressurized water reactor
SSFL	Santa Susana Field Laboratory
TRU	transuranic
UMC	University of Missouri at Columbia

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INTRODUCTION

The Private Sector Initiatives Program was started in mid-1987 under cognizance of the Office of the Deputy Assistant Secretary for Reactor Systems, Development Technology (NE-50). The purpose of the program is to utilize industrial ties between U. S. firms and their Japanese counterparts, to enhance U.S. access to advanced Japanese reactor programs, and ultimately, to provide a basis for U.S. vendor participation in advanced Japanese liquid metal reactor (LMR) designs. The program included participation from three U.S. vendors: General Electric Company, Westinghouse, and Rockwell. Rockwell's participation in the Private Sector Initiatives program was through its Rocketdyne Division. The Rocketdyne Division of Rockwell was acquired by Boeing in 1996, and Private Sector Initiatives activities formerly performed by Rocketdyne as part of Rockwell are now being concluded by Rocketdyne as part of Boeing.

Rocketdyne activities on the Private Sector Initiatives Program were implemented through an existing relationship with Kawasaki Heavy Industries (KHI). Rocketdyne and KHI reviewed their respective LMR research needs to identify and screen suitable areas for collaborative efforts. These areas were determined to be of mutual benefit and were approved by the Department of Energy (DOE) and Japan Atomic Power Company (JAPC). Rocketdyne and KHI performed their respective portions of tasks within these selected areas and exchanged results. Agreed-upon exchange areas for the Rocketdyne/KHI Private Sector Initiatives collaborative efforts were:

- Plant-type evaluations
- Shrouded inducer pump
- Inherent safe core
- Passive shutdown heat removal systems
- Booster tube steam generator
- Advanced piping
- Transuranic (TRU) partitioning
- Dry sodium removal

Results from prior year activities are reported in References 1 through 6.

SUMMARY

This report for calendar years 1993 through September 1998 describes efforts performed under the Private Sector Initiatives contract. The report also describes those efforts that have continued with private funding after being initiated under this contract.

The development of a pyrochemical process, called TRUMP-S, for partitioning actinides from PUREX waste, is described in this report. This effort is funded by the Central Research Institute of Electric Power Industry (CRIEPI), KHI, the United States Department of Energy, and Boeing.

TASK 1. PYROPARTITIONING PROCESS DEVELOPMENT

1.1 OBJECTIVE

The objective of this task was to develop and evaluate a pyropartitioning process to separate the actinides from PUREX wastes. The process goals were to separate >99% of each actinide from PUREX waste and concentrate the actinides into a product that is >90% actinides.

1.2 ACCOMPLISHMENTS

Pyropartitioning development activities were reported in technical reports[1-8] and several presentations and publications at national and international meetings.[9-36] During 1988 through 1994, the TRUMP-S pyropartitioning process electrochemical and physical data were measured and the actinides separation technique was developed and the actinide separation and product purity was demonstrated. These electrochemical and physical data are summarized in this report.

During 1994 through September 1997 the TRUMP-S process was demonstrated at a 1/6000 and 1/2000 scale of a plant required to process the PUREX waste generated by Japan's 800 tonne/yr PUREX reprocessing plant. The process was demonstrated at MURR by MURR, UMC, CRIEPI, KHI and Boeing personnel. The demonstration tests utilized simulated PUREX wastes consisting of nonradioactive components with actinides added in the proper proportions to simulate the waste generated when Japan's PUREX plant is processing 48,000 megaWatt day/tonne burnup PWR fuel.

The TRUMP-S pyropartitioning process separates PUREX residue into the four major groups of metals; (1) those metals more active than rare earths, (2) those metals more noble than actinides, (3) rare earths and (4) actinides. A consistent set of electrochemical and physical data were required to develop the pyropartitioning process; these data were measured and the TRUMP-S pyropartitioning process was developed and tested to show that actinides could be separated from PUREX wastes. Process demonstration tests demonstrated that it was indeed possible to separate >99% of the actinides from simulated PUREX wastes and concentrate them into a product that is >90% actinides.

A process engineering feasibility study was conducted. The results of this engineering feasibility study indicated that it was not only feasible to design a TRUMP-S pyropartitioning plant but such a plant could be designed with today's technology assuming reasonably expected results from near term technology development programs. This study indicated the plant could be safeguarded to prevent diversion of SNM materials to comply with national and international regulatory agencies. This study also suggested readily prepared waste forms for the pyropartitioned products that would not only enhance environmental isolation of the nuclear waste fractions produced during pyropartitioning but also suggested potential waste management options that could significantly reduce waste management costs.

Computer programs were developed to simulate the pyropartitioning process. These computer models were exhaustively tested to assure that they effectively modeled the process as developed and that the computer predicted product separations and purity which agreed with experimentally verified observations. This computer code can be utilized to evaluate potential process improvements and process upsets.

1.3 PROCESS DESCRIPTION

The TRUMP-S process development program has been concluded and this will be the final Private Sector Initiatives Report that will discuss this process. Therefore this report will not only describe calendar year 1993 through September 1998 progress but also summarizes the electrochemical and physical property data upon which the pyropartitioning process was based even though some of these data were reported prior to January 1993. The TRUMP-S program was a multiyear program with specific objectives for each period as indicated in Table 1.

The flow diagram of the pyropartitioning process to separate actinides from PUREX wastes consists of the following steps: (1) microwave denitration and solidification, (2) chlorination to convert oxides to chlorides, (3) dissolution of the PUREX residue chlorides in molten LiCl-KCl eutectic solvent, (4) reductive extraction and removal of the noble metals from the molten salt phase, (5) reductive extraction to remove the actinides and rare earths from active metals followed by electrorefining to remove the U and (6) reductive extraction followed by electrodeposition to separate the remaining TRUs from the rare earths. The MURR/UMC/CRIEPI/ KHI/Boeing group only developed the pyropartitioning steps (steps 4, 5 and 6) of the process. CRIEPI and its other subcontractors developed the non pyropartitioning portion of the process.

Table 1. CRIEPI/KHI/Boeing TRUMP-S Program Objectives.

JFY	Objectives
1986	Evaluate feasibility of pyrochemically partitioning transuranics from PUREX waste.
1987	Develop preliminary economics of pyrochemically partitioning transuranics from PUREX waste.
1988-1990	Measure chemical and electrochemical properties of actinides and rare earths to predict actinide separation efficiency and purity for pyrochemical partitioning
1991-1993	Determine americium electrochemical properties and measure actinide separation efficiency and product purity for pyrochemical partitioning of PUREX waste.
1994-1997	Process demonstration of pyropartitioning steps, develop a computer code to model the process as developed and to perform a pyropartitioning process engineering feasibility study.

The purpose of developing the TRUMP-S pyropartitioning process to separate the actinides from nuclear waste was part of Japan's OMEGA program to re-evaluate the nuclear fuel cycles as an option to assure a continuous supply of electrical power in the future. The pyropartitioned actinide product could then be transmuted into stable products, stored, or placed in a minimal volume waste form for repository disposal. Although partitioning/transmutation (P/T) may not eliminate the need for repository long-term environmental isolation of spent fuel reprocessing waste, P/T should reduce the amount of actinide waste requiring repository isolation. This should markedly reduce the waste management costs associated with nuclear power generation.

1.4 CHEMICAL BASIS FOR THE TRUMP-S PYROPARTITIONING PROCESS

The pyropartitioning capability of the TRUMP-S process depends on the difference in electrochemical activity of the metallic components of chlorinated PUREX waste in the process solvents of molten LiCl-KCl salt eutectic and/or molten Cd or Bi. The transuranic actinides (primarily Np, Pu, Am and Cm) are the high activity actinides and are the actinide components which specify the TRU content of low level waste. If the TRU content of nuclear waste is less than 10 nanoCuries/gm of alpha emitting TRU's and meets certain other requirements of waste composition, stability and leachability, the waste may be disposed of in a low-cost, non-repository, near-surface radioactive waste disposal site. Near surface disposal is about a factor of 50 less expensive than actinide repository disposal. Thus there is a significant economic incentive to minimize waste which must be disposed in a repository.

1.5 ACTINIDE AND RARE EARTH CHEMICAL AND PHYSICAL PROPERTIES

To develop the TRUMP-S pyropartitioning process, a self consistent set of actinide and rare earth chemical and physical properties data were required; these data were measured in the process solvents. These measured properties are summarized in the tables below and have been reported in technical reports[1-8], papers and publications.[9-36] Some of these measured properties are also compared to literature values[37-80] where available. From these data the standard free energies of formation and activity coefficients of the actinides and rare earths in the process solvents were calculated. These data are given in Tables 2-6 and were used to determine the theoretical ability of pyropartitioning to separate the actinides from the other components in PUREX wastes.

Distribution coefficient measurements of actinide and rare earths in the solvent systems confirmed separation predictions based on free energy and activity coefficient data. These data are given in Tables 7 and 8 and generally agree with literature values(57) where available. The mole fraction solubilities of rare earths and actinides in molten Cd and Bi are given in Table 9. Electrodeposition studies confirmed that electrodeposition rates were not constrained by decomposition of either salt or metal complexes in the metal/salt system. From these data the salt/Cd Heterogeneous Rate Constants were developed and are given in Table 10.

From the preceding data, graphs of the potential lines of actinide and rare earths in the molten salt, molten salt/Cd and molten salt/Bi systems were developed; these data are given in Figures 1-3. These data were also used to graph interfacial potentials of the actinides and rare earths at various concentrations; these interfacial potentials for the actinides are given for the salt/Cd and salt/Bi systems in Figures 4 and 5 respectively. These potential data are reported versus the Ag/AgCl reference electrode used in this program. The Ag/AgCl reference electrode was fabricated from a 1.275 wt.% mixture of AgCl in LiCl-KCl eutectic. To convert the potentials versus the Ag/AgCl reference to the potentials versus the Cl^-/Cl_2 reference, one must subtract 1.204, 1.213 and 1.220 V from the 400°, 450° and 500°C Ag/AgCl referenced potentials respectively.

The Am and Nd electrochemical deposits appear to be in equilibrium with the divalent state in the LiCl-KCl eutectic. However, when Am or Nd is present as dissolved metal in Cd or Bi, their cations in LiCl-KCl eutectic are either partially or primarily trivalent. Although several of the other rare earths exhibit a slight divalent character in metal/salt solutions, they are primarily in the trivalent state in these metal/salt systems. Both Sm and Eu are in the divalent state exclusively in these systems because their standard potentials in these systems are sufficiently negative to reduce the Li from LiCl salt solvents.

1.6 SUMMARY OF PROCESS DEMONSTRATION TEST RESULTS

TRUMP-S separation process steps were demonstrated in integrated 1/6000 and 1/2000 scale tests. These tests demonstrated that all process goals could be achieved by implementing the present process, which consists of reductive extraction for separation of noble and active metals, electrorefining for U recovery, bismuth extraction for TRU/rare earth separation, and electrorefining for TRU recovery.

Demonstration tests showed that >99.9% of the actinides could be separated from the noble and active metals by reductive extraction in the LiCl-KCl/Cd system. The electrorefining step demonstrated U recovery with <1% rare earth content in the deposit. The bismuth extraction process demonstrated >99.4% actinide recovery in a bismuth product with a TRU/rare earth mole ratio of 1.20, exceeding the targets of 99% recovery and TRU/rare earth mole ratio of 1. The TRU recovery electrorefining step showed that >99.8% of each TRU could be stripped from the bismuth extraction product onto a solid cathode.

In summary these demonstration tests exceeded the process goals of 99% actinide removal from simulated PUREX wastes into an actinide product that is >90% actinides.

Table 2. Free Energies of Formation and Activity Coefficients for Rare Earth Chlorides in LiCl/KCl.

Element	Temperature (°C)	$-\Delta G^0_{exp}$ (kJoules/ mole)	$-E^0$ (1) Cl_2/Cl^- (Volts)	n(2)	$-\Delta G^{0(3)}_{cryst}$ (kJoules/ mole)	$\Delta G^{0(4)}_{fus}$ (kJoules/ mole)	$-\Delta G^0_{liq}$ (kJoules mole)	Activity Coefficient (γ_{MCl_3})	
								Crystal(5)	Liquid(5)
$LaCl_3$	400	915.8	3.164	--	904.2	18.4	885.9	$1.3x10^{-1}$	$4.8x10^{-3}$
	425	911.7	3.150	--	898.7	17.6	881.2	$1.1x10^{-1}$	$5.3x10^{-3}$
	450	907.9	3.137	3.2	892.9	16.7	876.1	$8.2x10^{-2}$	$5.0x10^{-3}$
$NdCl_2$	400	588.3	3.049	2	583.8(6)	10.9(4)	572.9	$4.5x10^{-1}$	$6.4x10^{-2}$
	425	585.3	3.033	2	579.9(6)	10.1(4)	569.8	$3.9x10^{-1}$	$6.9x10^{-2}$
	450	582.0	3.016	2	576.3(6)	9.5(4)	566.8	$3.9x10^{-1}$	$7.9x10^{-2}$
$GdCl_3$	400	894.1	3.089	3	842.7	8.8	833.9	$1.0x10^{-4}$	$2.1x10^{-5}$
	425	889.5	3.073	3	836.8	7.5	829.3	$1.1x10^{-4}$	$3.1x10^{-5}$
	450	884.5	3.056	3	831.4	6.7	824.7	$1.4x10^{-4}$	$4.7x10^{-5}$
$PrCl_3$	400	902.9	3.119	3	889.5	18.0	871.5	$9.1x10^{-2}$	$3.7x10^{-3}$
	425	897.9	3.102	3	883.2	17.2	866.5	$7.9x10^{-2}$	$4.5x10^{-3}$
	450	892.9	3.085	3	877.8	15.9	861.9	$8.1x10^{-2}$	$5.8x10^{-3}$
YCl_3	400	913.8	3.156	3	840.2	8.8	831.4	$1.9x10^{-6}$	$4.0x10^{-7}$
	425	909.2	3.140	3	834.7	7.9	826.8	$2.7x10^{-6}$	$6.8x10^{-7}$
	450	904.2	3.124	3	828.9	7.5	821.3	$3.6x10^{-6}$	$1.0x10^{-6}$
$CeCl_3$	400	901.2	3.113	2.7	884.9	16.7	868.2	$5.4x10^{-2}$	$2.7x10^{-3}$
	425	899.6	3.108	2.9	879.1	15.9	863.2	$2.9x10^{-2}$	$1.9x10^{-3}$
	450	897.1	3.099	3.0	873.2	15.1	858.1	$1.9x10^{-2}$	$1.5x10^{-3}$

(1)Measured and from ΔG^o; $-\Delta G^o_f/3F$.; (2)Fusselman from experimental slope of voltage/Log X data; (3)Pankratz(44); (4)Heredy, private communication; (5)Standard state basis; (6)Roine(80)

Table 3. Free Energies of Formation and Activity Coefficients for Actinide Chlorides in LiCl/KCl.

Element	Temperature (°C)	$-\Delta G^{o}_{exp}$ (kJoules/ mole)$^{(1)}$	$-E^{o}$ (2) Cl_2/Cl^- (Volts)	n(3)	$-\Delta G$ (4) (kJoules/ mole)	ΔG(4) (kJoules/ mole)	$-\Delta G^{o}_{liq}$ (kJoules mole)	Activity Coefficient (γ_{MCl_3})	
								Crystal$^{(5)}$	Liquid$^{(5)}$
UCl_3	400	731.7	2.528	3.36	713.7	18.1	695.6	4.0×10^{-2}	1.6×10^{-3}
	425	725.0	2.505	3.06	708.4	17.1	691.4	5.8×10^{-2}	3.0×10^{-3}
	450	723.1	2.498	3.25	703.3	16.2	687.1	3.7×10^{-2}	2.5×10^{-3}
	500	714.4	2.468	--	692.9	13.9	678.9	3.5×10^{-2}	4.0×10^{-3}
$NpCl_3$									
	400	788.8	2.725	2.93	750.4	20.3	730.0	1.0×10^{-3}	2.8×10^{-5}
	425	785.6	2.714	3.31	745.1	19.1	726.0	9.3×10^{-4}	3.5×10^{-5}
	450	781.0	2.698	3.24	739.6	17.7	721.9	1.0×10^{-3}	5.4×10^{-5}
	500	772.3	2.668	3.14	728.8	15.2	713.6	1.1×10^{-3}	1.1×10^{-4}
$PuCl_3$									
	400	823.5	2.845	--	806.0	22.1	783.9	4.4×10^{-2}	8.0×10^{-4}
	425	818.3	2.827	2.91	800.2	20.6	779.6	4.4×10^{2}	1.3×10^{-3}
	450	812.8	2.808	2.88	794.5	19.1	775.5	4.8×10^{-2}	2.0×10^{-3}
	500	803.2	2.775	3.01	783.1	16.1	767.1	4.4×10^{-2}	3.6×10^{-3}
$AmCl_3$									
	400	825.2	2.851	3	819.5$^{(6)}$	15.4	804.1	3.6×10^{-1}	2.3×10^{-2}
	450	818.7	2.829$^{(7)}$	3	808.0$^{(6)}$	13.0	795.0	2.8×10^{-1}	1.9×10^{-2}
	500	805.7	2.784$^{(7)}$	3	798.6$^{(6)}$	10.6	788.0	3.3×10^{-1}	6.4×10^{-2}
$AmCl_2$									
	400	552.9	2.865$^{(7)}$	2.0	556.6$^{(6)}$	10.2$^{(6)}$	546.4	1.9	3.1×10^{-1}
	450	550.5	2.853$^{(7)}$	2.0	547.4$^{(6)}$	8.7$^{(6)}$	538.7	6.0×10^{-1}	1.4×10^{-2}
	500	547.6	2.838$^{(7)}$	2.0	539.4$^{(6)}$	7.0$^{(6)}$	532.4	2.8×10^{-1}	9.4×10^{-2}

(1)n=3 basis, (2) $\Delta G^{o}/3F$, (3) data exhibits scatter, (4) Pankratz(44), (5) liquid/crystal standard states, (6)Heredy private communication,

(7) Fusselman, private communication.

Table 4. Activity Coefficients for Rare Earths* in Cadmium at 450°C.

Element	Rocketdyne Data	Johnson and Yonco(48)
Y	$3\text{x}10^{-7}$	-
La	$4\text{x}10^{-10}$	$5\text{x}10^{-10}$
Ce	$3\text{x}10^{-10}$	$14\text{x}10^{-10}$
Nd	$7\text{x}10^{-9}$	-
Pr	$2\text{x}10^{-9}$	$3\text{x}10^{-9}$
Gd	$4\text{x}10^{-8}$	-

*Near saturation conditions except for Y where $X = 6.9\text{x}10^{-3}$

Table 5. Activity Coefficients for Saturated Solutions of Actinides Dissolved in Cadmium.

Element	Temperature (°C)	Rocketdyne Activity Coeff. (γ)	Johnson et al.(45-47) Activity Coeff. (γ_{liq})	Johnson et al.(45-47) Cd Solubility (mole fraction, X)
U	400		52	$2.5\text{x}10^{-3}$
	425		63	$4.4\text{x}10^{-3}$
	450	15	82	$7.6\text{x}10^{-3}$
	500		94	$1.4\text{x}10^{-2}$
Np	400		$1.8\text{x}10^{-3}$	$3.7\text{x}10^{-3}$
	425		$3.4\text{x}10^{-3}$	$6.3\text{x}10^{-3}$
	450		$6.1\text{x}10^{-3}$	$1.0\text{x}10^{-2}$
	500		$1.9\text{x}10^{-2}$	$2.2\text{x}10^{-2}$
Pu	400		$1.4\text{x}10^{-5}$	$7.2\text{x}10^{-3}$
	425		$3.0\text{x}10^{-5}$	$9.1\text{x}10^{-3}$
	450	$3.1\text{x}10^{-5}$	$6.2\text{x}10^{-5}$	$1.2\text{x}10^{-2}$
	500		$2.1\text{x}10^{-4}$	$1.8\text{x}10^{-2}$
Am	450	10^{-4}		

Table 6. Activity Coefficients of Rare Earths and Actinides in Molten Bi

Element	Temp°C	T715	CRIEPI(59)	Literature	Reference
Y	450	--	--	$2.8x10^{-12}$	44
	500	--	$6.8x10^{-11}$	$1.7x10^{-11}$	55
La	450	$4.7x10^{-14}$	--	$3.0x10^{-15}$	41a
	500	--	$3.6x10^{-14}$	$4.1x10^{-14}$	53
Ce	450	$1.4x10^{-13}$	--	$1.8x10^{-13}$	43b
	500	--	$1.0x10^{-13}$	$1.9x10^{-13}$	43
Pr	450	$2.2x10^{-13}$	--	--	--
	500	--	$1.5x10^{-13}$	$3.0x10^{-13}$	56
Nd	450	$6.3x10^{-12}$	--	--	--
	500	--	$1.4x10^{-13}$	$3.8x10^{-13}$	57
Sm	450	--	--	--	--
	500	--	--	$3.3x10^{-14}$	61
Eu	450	--	--	--	--
	500	--	--	$2.7x10^{-12}$	62
Sm	450	--	--	--	--
	500	--	$7.2x10^{-12}$	$3.0x10^{-12}$	58
U	450	--	--	$1.2X10^{-5}$	53c
	500	--	$2.2x10^{-5}$	$2.7x10^{-5}$	53
Np	450	$6.4x10^{-8}$	--	--	--
	500	--	$4.0x10^{-8}$	--	--
Pu	450	$4.7x10^{-10}$	--	$8.5x10^{-11}$	38
	500	--	--	$4.5x10^{-10}$	38
Am	450	$2.2x10^{-10}$	--	--	--
	500	$2.3x10^{-10}$	--	--	--

a. $3x10^{-15}$ (42), b. $2x10^{-14}$ (43), c. 2x10-^{5} (42)

Table 7. Distribution Coefficients for Actinides and Rare Earths (Relative to Nd) in Molten LiCl-KCl/Cd Systems.

Element	Separation Test	Activity Tests	Distribution Tests	CRIEPI	ANL
U	0.008-0.013	0.006	0.022	0.024	0.022
Np	0.022-0.033	N/A	0.056	0.050	0.042
Pu	0.039-0.052	0.035	0.040	N/A	0.040
Am	0.043-0.054	0.023	0.024-0.067	N/A	0.073
Nd	1.0	1.0	1.0	1.0	1.0
Ce	1.13-1.20	0.47	0.9	1.10	1.22
La	3.2-3.7	3.7	2.3	3.1	2.5
Pr	0.77	0.91	N/A	0.86	1.58
Y	28-39	45	N/A	114	78
Gd	0.69-1.28	3.3	3.1	N/A	5.6

Table 8. Distribution Coefficients for Actinides and Rare Earth (Relative to Nd) in Molten LiCl-KCl/Bi Systems.

Element	Rocketdyne Data	CRIEPI Data
U	0.0008	0.00091
Np	0.0056	0.0095
Pu	0.0080	0.012*
Am	0.0159	0.014*
Nd	1.0	1.0
Ce	1.14	0.91
La	2.9	2.8
Pr		0.77
Y		710
Gd	13	11

* estimated values.

Table 9. Mole Fraction Solubility of Rare Earths and Actinides in Molten Cd and Bi

		Cadmium			**Bismuth**			
Element	**Temp°C**	**TI22**	**Literat.**	**Referen**	**SPF**	**Referen**	**Literat.**	**Referen**
Y	450	0.0083	--	--	0.0005	40	--	--
	500	--	--	--	0.0008	40	--	--
La	450	0.0009	0.009	54	0.0051	40	0.0050	54
	500	--	--	--	0.0083	40	--	--
Ce	450	0.0018	0.0018	43	0.0040	40	0.0033	43
	500	--	--	--	0.0067	40	--	--
Pr	450	0.0030	--	--	0.0046	40	--	--
	500	--	--	--	0.0082	40	--	--
Nd	450	0.0050	--	--	0.0028	40	--	--
	500	--	--	--	--	--	--	--
Gd	450	0.0400	--	--	--	--	--	--
	500	--	--	--	--	--	--	--
U	450	0.0076	0.0077	54	0.0027	39	<0.0066	53
	500	--	0.014	--	0.0045	39	0.0043	--
NP	450	0.0104	0.010	--	--	--	--	--
	500	--	0.022	--	--	--	--	--
PU	450	0.0115	0.012	38	0.0064	38	0.0066	38
	500	--	0.018	--	0.0117	38	0.012	--
Am	450	0.018	0.0094	--	0.0009	--	--	--
	500	--	0.0040	--	0.0019	--	--	--

Table 10. Heterogeneous Rate Constant Values for Actinides and Rare Earths in Liquid Cadmium and at Solid Cathodes at 450°C.

Element	Rate Constant (mA/cm^2) in Liquid Cadmium	Rate Constant (mA/cm^2) at a Solid Cathode
U		140
Np	805	180
Pu	410	170
Am	--	130
Gd	7600	120
La	3500	--
Y	213	--

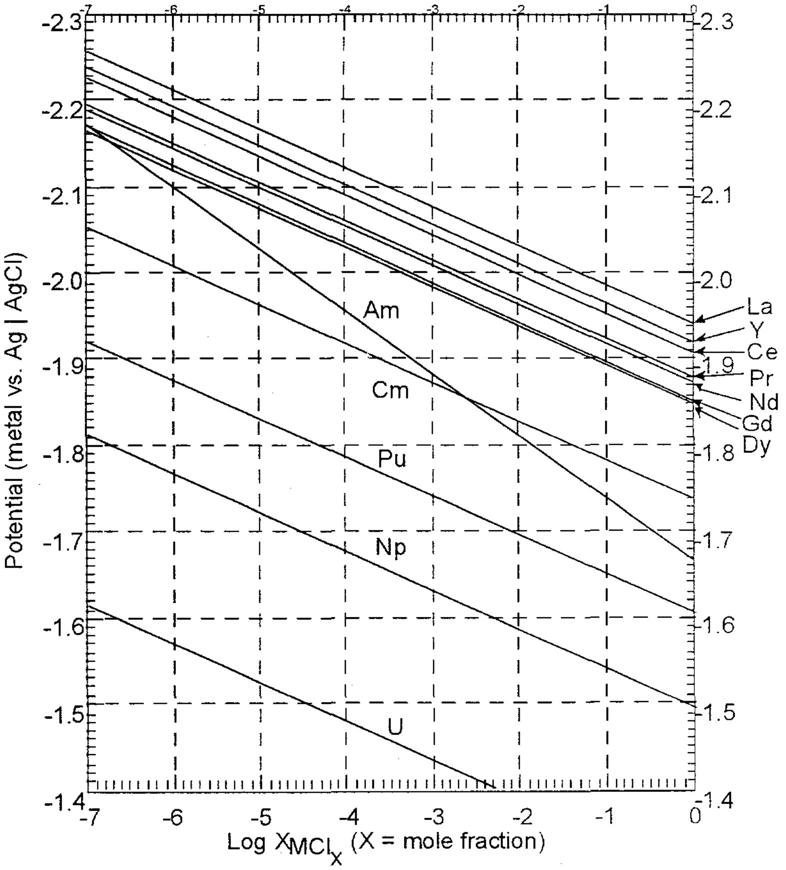

Figure 1. M|MCl$_x$ Potential Lines

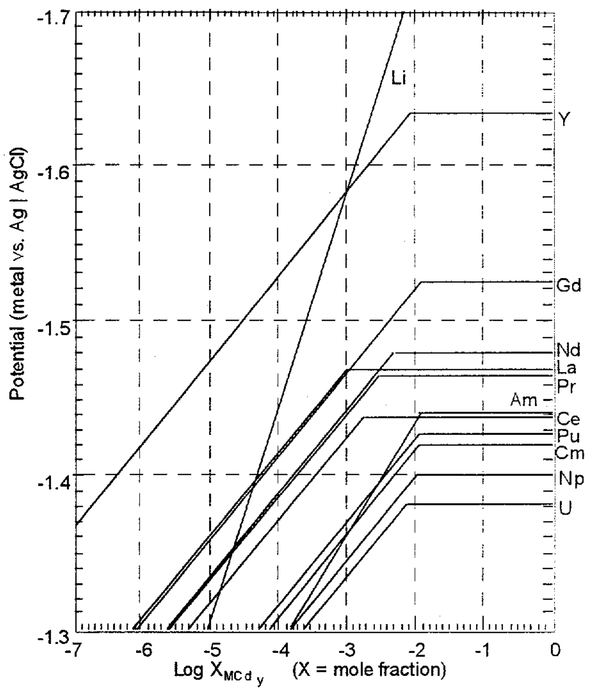

Figure 2. $MCd_y|MCl_x$ **Potential Lines (Log** X_{MClx} **= -2.65)**

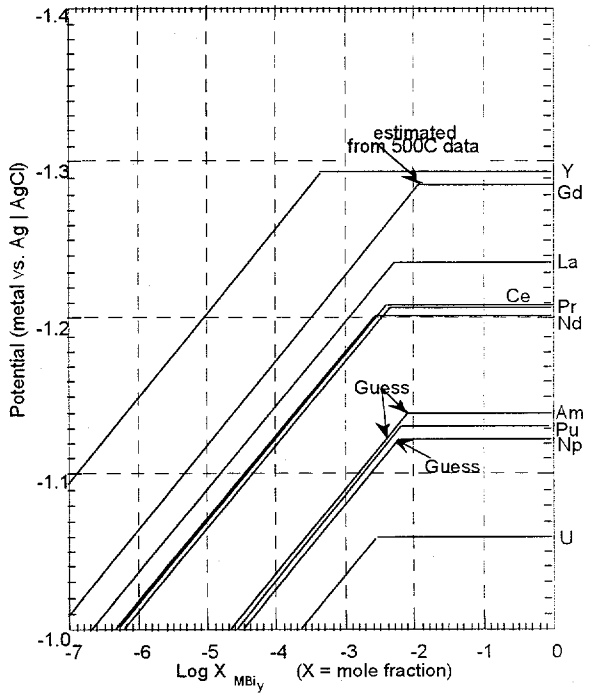

Figure 3. $MBi_y|MCl_x$ **Potential Lines (Log** X_{MClx} **= -2.65)**

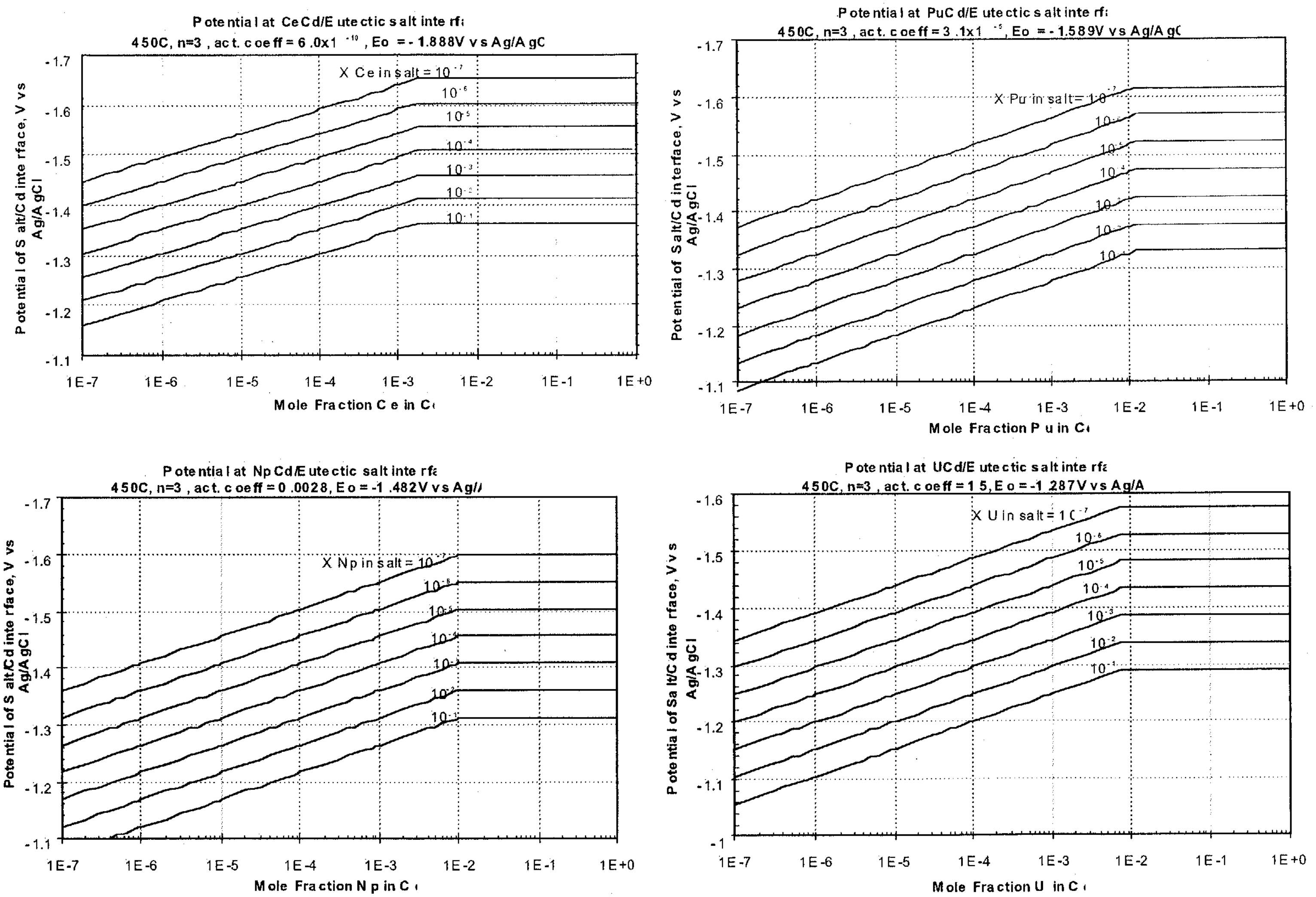

Figure 4 Actinide Potentials at the M_{Cd}/MCl_x-LiCl-KCl Eutectic Interface

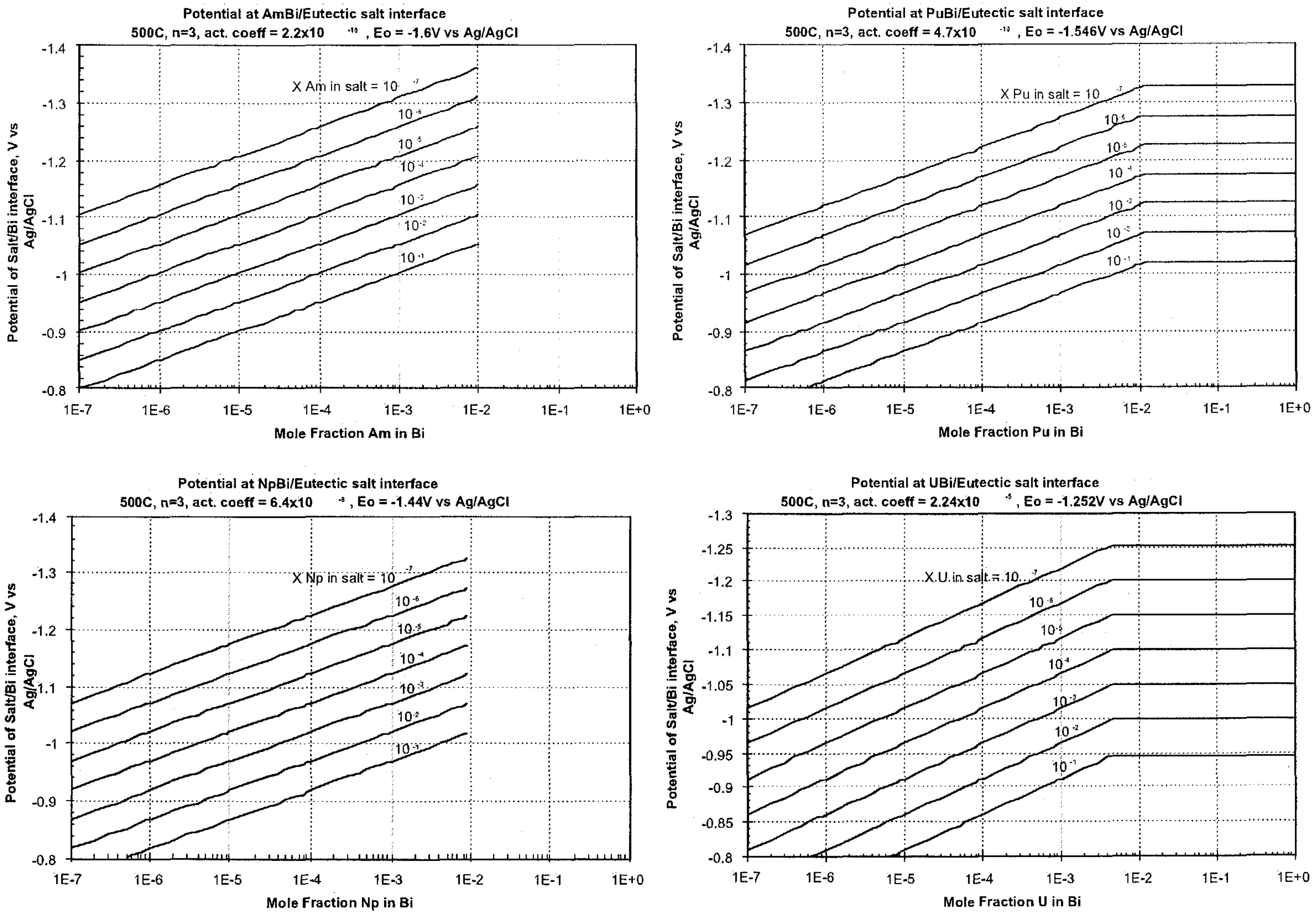

Figure 5 Actinide Potentials at the M_{Bi}/MCl_x-LiCl-KCl Eutectic Interface

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