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**Technical Progress Report
Private Sector Initiatives Between
the United States and Japan**

January 1989 - December 1989

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Rockwell International
Rocketdyne Division

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CONTENTS

TASK 1. SHROUDED INDUCER PUMP	1
1.1 OBJECTIVE	1
1.2 ACCOMPLISHMENTS	1
1.3 PLANNED FUTURE WORK	2
1.4 BENEFITS	2
TASK 2. TRU PARTITIONING	3
2.1 OBJECTIVE	3
2.2 ACCOMPLISHMENTS	3
2.2.1 Rare Earth Experimental Results	3
2.2.2 Actinide Electrochemical Data	7
2.3 PROGRAM SUMMARY	7
TASK 3. PARTITIONING-TRANSMUTATION REVIEW	10
3.1 OBJECTIVE	10
3.2 ACCOMPLISHMENTS	10

TABLES

1. Free Energy Calculations	4
2. Activity Coefficient Calculations	5
3. Divalent/Trivalent Rare Earths Data at 450°C	6
4. Activity Coefficients for Lanthanides in Cadmium at 450°C	6

FIGURES

1. TRUMP-S Actinide System	8
2. TRUMP-S Glove Box Viewed from Control Gallery	9

INTRODUCTION

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The Private Sector Initiatives Program was started in mid-1987 under the cognizance of the Office of the Deputy Assistant Secretary for Reactor Systems, Development Technology (NE-50). The purpose of this 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 includes participation from the three U.S. vendors: General Electric Company, Rockwell International, and Westinghouse.

Rockwell activities on the Private Sector Initiatives Program were implemented through an existing relationship with Kawasaki Heavy Industries (KHI). Rockwell 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). Rockwell and KHI performed their respective portions of tasks within these selected areas and exchanged results. Currently, agreed-upon exchange areas for the Rockwell/KHI private sector initiatives collaborative efforts are

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

SUMMARY

This annual report for calendar year 1989 describes the efforts performed under the Private Sector Initiative contract. The report also describes those efforts that have continued with private funding after being initiated under this contract.

✓ Two privately funded, continuing activities are described In Tasks 1 and 2. The first task is the development of the shrouded inducer pump, which is funded by the Japan Atomic Power Company, Kawasaki Heavy Industries, and Rockwell International. The second task is the development of a pyrochemical process, called TRUMP-S, for partitioning actinides from PUREX waste. This effort is funded by the Central Research Institute for Electric Power Industry, Kawasaki Heavy Industries, and Rockwell International.

Private Sector Initiative contract funds in 1989 were concentrated on the preparation of a report reviewing and evaluating partitioning and transmutation technology. This effort is described in Task 3.

TASK 1. SHROUDED INDUCER PUMP

1.1 OBJECTIVE

The objective of this task is to develop a shrouded inducer pump for the Demonstration Fast Breeder Reactor. The expectations are that the pump can be adapted to the requirements of other advanced liquid metal reactor plants with little or no design modification. Successful completion of this scale-model pump development phase is expected to lead to a full-scale pump prototype design, fabrication, and test program.

1.2 ACCOMPLISHMENTS

Results of prior year activities are reported in the 1987 and 1988 Private Sector Initiative annual reports (References 1 and 2). In early 1989 it became clear that the original shrouded inducer pump concept, of an inducer followed by a mixed flow diffuser, required significant modifications to overcome two problems in performance. The performance problems were low developed head, due to separation in the diffuser, and dye removal on the inducer, indicating possible cavitation damage in sodium operation. The basic design solution adopted was to reduce the tip speed of the inducer, compensate for the resultant loss of rotor head with the addition of a second inducer blade row (called a kicker), and diffuse the flow axially before turning it.

A concentrated effort was undertaken for the balance of the year to develop and design the hardware needed to implement this new approach and to supply modified hardware for the 1/5-scale water test pump in Akashi, Japan. The following activities were performed in 1989:

1. Inducer discharge flow angles were measured with a laser velocimeter both radially and circumferentially relative to the inducer flow channel as input to the design of the kicker.
2. Three kickers were designed, a shrouded and an unshrouded cylindrical kicker and a bell kicker.
3. The two cylindrical kickers were tested 1/6 scale in water. Optimum kicker-inducer clocking of the blades was determined. Based on their performance, the unshrouded design was selected for the cylindrical kicker. The kicker was trimmed to match the rotor head requirement. Dye tests were performed to verify that the rotor was free from cavitation damage. The discharge flow angle of the kicker was measured for input to the stator design.

4. Axial diffusing systems were designed for both the cylindrical and bell kicker concepts. The stator for the cylindrical kicker diffusing system was tested 1/6 scale in water, and the diffusing systems for both the cylindrical kicker and the bell kicker were tested in air. (The air test for the bell kicker diffusing system was performed by KHI.)
5. Hardware was designed and fabricated to allow modification of the 1/5-scale pump for testing of both the cylindrical kicker and the bell kicker.

1.3 PLANNED FUTURE WORK

The modified 1/5-scale hardware will be performance tested in 1990 at KHI's pump test facility in Akashi. The tests of the cylindrical kicker configuration will incorporate improvements identified in the 1989 water tunnel tests, including kicker trim to match headrise, kicker clocking relative to the inducer, kicker-stator axial spacing, and stator leading edge angle adjustments. The Akashi tests will provide the basis for selecting either the cylindrical vs bell kicker configuration for the shrouded inducer pump.

1.4 BENEFITS

The shrouded inducer pump provides a small, compact primary system pump that is essential to achieving a compact reactor assembly and the overall goal of an economic LMR design. The activities described will help achieve the development of a pump for the advanced LMR plant.

TASK 2. TRU PARTITIONING

2.1 OBJECTIVE

The overall objective of the Rockwell International/Kawasaki Heavy Industries/Central Research Institute of the Electric Power Industry (Rockwell/KHI/CRIEPI) program is to develop a process to recover 99% of the remaining TRU materials (Np, Pu, Am, Cm) from PUREX waste to simplify nuclear waste management. The purpose of the program is to separate the high-level nuclear waste into a TRU-rich stream and a TRU-depleted stream to reduce waste management costs. The TRU-rich stream could be stored indefinitely or, if sufficiently pure, could be fissioned in a fast reactor and, thereby, convert a large fraction of the waste to a low-TRU, high-level waste (HLW). After storage of the depleted TRU HLW for a period of time to allow the fission products to decay to low levels, this waste could be disposed of as low-level waste (LLW) at substantially reduced costs compared to TRU waste.

2.2 ACCOMPLISHMENTS

2.2.1 Rare Earth Experimental Results

2.2.1.1 Free Energy of Formation

Calculation of the free energy of formation of the rare earth chloride and the activity coefficient of that salt in the electrolyte requires the measurement of the voltage between the parent metal and the Ag/AgCl reference electrode as a function of the concentration of the rare earth chloride for any specified temperature. The activity of the rare earth metal in cadmium is determined by measuring the voltage between the rare earth metal and the cadmium-metal mixture having a known composition.

Calculations were made for free energies and activity coefficients based on both the hypothetical liquid state and the crystalline standard states. The results of these calculations appear in Tables 1 and 2.

In Table 2 the experimental ΔG° of formation is given in column 3, while the thermodynamic ΔG° of formation are given in columns 4 and 6 for the crystalline and hypothetical liquid standard states, respectively. The activity coefficients for the active metal trichloride in LiCl-KCl electrolyte in the crystalline and hypothetical liquid standard states are given in columns 7 and 8, respectively, in Table 2.

Europium and samarium metals were added to the LiCl-KCl electrolyte, and it was verified that lithium was released as these rare earths formed the divalent chlorides. Since

Table 1. Free Energy Calculations

Element	Temperature (°C)	E_1^1	E_2^2	E_3^3	E_4^4	$E_{MCl_3}^5$	ΔG_f° (Exp'l.)
La	400	1.963	0.893	0.310	-0.002	3.164	218.9
	425	1.947	0.884	0.321	-0.002	3.150	217.9
	450	1.931	0.875	0.333	-0.002	3.137	217.0
Nd	400	1.853	0.893	0.310	-0.002	3.054	211.3
	425	1.836	0.884	0.321	-0.002	3.039	210.3
	450	1.814	0.875	0.333	-0.002	3.020	208.9
Gd	400	1.886	0.893	0.310	-0.002	3.087	213.6
	425	1.862	0.884	0.321	-0.002	3.065	212.1
	450	1.838	0.875	0.333	-0.002	3.044	210.6
Pr	400	1.919	0.893	0.310	-0.002	3.120	215.9
	425	1.901	0.884	0.321	-0.002	3.104	214.8
	450	1.890	0.875	0.333	-0.002	3.096	214.2
Y	400	1.903	0.893	0.310	-0.002	3.104	214.8
	425	1.888	0.884	0.321	-0.002	3.091	213.9
	450	1.880	0.875	0.333	-0.002	3.086	213.5
Ce	400	1.912	0.893	0.310	-0.002	3.113	215.4
	425	1.905	0.884	0.321	-0.002	3.108	215.0
	450	1.893	0.875	0.333	-0.002	3.099	214.4

¹ E_1 = cell voltage extrapolated to $X_{MCl_3} = 1$ ⁴ E_4 = correction for Ta/Ag thermal potential

² $E_2 = E^\circ_{AgCl}$

⁵ $E^\circ_{MCl_3}$ = sum of E_1 through E_4

³ $E_3 = \frac{RT}{F} \ln X_{AgCl}$; $X_{AgCl} = 0.00481$

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Table 2. Activity Coefficient Calculations

Element	Temperature (°C)	$-\Delta G^\circ_{\text{exp}}$ (Kcal/mole)	$-\Delta G^\circ_{\text{cryst}}^1$ (Kcal/mole)	ΔG_{fus}^2 (Kcal/mole)	$-\Delta G^\circ_{\text{llq}}$ (Kcal/mole)	Activity Coefficient (γ_{MCl_3})	
						Crystal ³	Liquid ³
La	400	218.9	216.1	4.4	211.7	1.2×10^{-1}	4.6×10^{-3}
	425	217.9	214.8	4.2	210.6	1.1×10^{-1}	5.2×10^{-3}
	450	217.0	213.4	4.0	209.4	8.2×10^{-2}	5.0×10^{-3}
Nd	400	211.3	209.3	3.9	205.4	2.2×10^{-1}	1.2×10^{-2}
	425	210.3	207.9	3.6	204.3	1.8×10^{-1}	1.3×10^{-2}
	450	208.9	206.6	3.4	203.2	2.0×10^{-1}	1.9×10^{-2}
Gd	400	213.6	201.4	2.1	199.3	1.1×10^{-4}	2.4×10^{-5}
	425	212.1	200.0	1.8	198.2	1.6×10^{-4}	4.4×10^{-5}
	450	210.6	198.7	1.6	197.1	2.5×10^{-4}	8.3×10^{-5}
Pr	400	215.9	212.6	4.3	209.0	8.5×10^{-2}	5.7×10^{-3}
	425	214.8	211.2	4.1	207.8	7.5×10^{-2}	6.4×10^{-3}
	450	214.2	209.8	3.8	206.7	4.7×10^{-2}	5.4×10^{-3}
Y	400	214.8	200.8	2.1	198.7	2.8×10^{-5}	5.9×10^{-6}
	425	213.9	199.5	1.9	197.6	3.1×10^{-5}	7.9×10^{-6}
	450	213.5	198.1	1.8	196.3	2.2×10^{-5}	6.3×10^{-6}
Ce	400	215.4	211.5	4.1	207.2	5.4×10^{-2}	2.2×10^{-3}
	425	215.0	210.1	3.9	206.1	2.9×10^{-2}	1.6×10^{-3}
	450	214.4	208.7	3.7	204.9	1.9×10^{-2}	1.3×10^{-3}

¹Bureau of Mines data

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²Calculated from specific heat data³Standard state basis

these rare earth chlorides are more stable than lithium chloride, they will not enter into the separation of actinides from rare earths.

2.2.1.2 Divalent State

Preliminary divalent/trivalent data were obtained for cerium and lanthanum (Tests 9 and 38). These data are given in Table 3. The percent of the rare earths existing as dichloride in equilibrium with the metal and trichloride in LiCl-KCl electrolyte is approximately 33 and 23%, respectively. The negative free energy of formation of the divalent chloride appears to be about 2 Kcal/equivalent less negative than the trivalent chloride. Later experiments, believed to be more accurate, indicated the ratios of the divalent to trivalent chloride were less than half the values shown in Table 3.

Table 3. Divalent/Trivalent Rare Earths Data at 450°C

Test	Rare Earth	Triple Point (moles)		K eq.	RT ln K	ΔG (kcal/mole)		$-\Delta G$ (kcal/eq.)			$M^{+2} + M^{+3}$ (%)
		M^{+2}	M^{+3}			M^{+3}	M^{+2}	M^{+3}	M^{+2}	Diff.	
9	Ce	0.00134	0.00269	3.77×10^{-4}	-11.3	214.4	139.2	71.5	69.6	1.9	33.3
38	La	0.00111	0.00367	1.11×10^{-4}	-13.1	217.0	140.3	72.3	70.2	2.1	23.2

2.2.1.3 Activity Coefficient of Rare Earth Metals in Cadmium Solvent

The activity coefficients for rare earth metals in cadmium solvent are given in Table 4. Good agreement is observed between Rockwell's data and the literature data, with Rockwell's data slightly less than the literature. The less satisfactory agreement for Ce is consistent with the experimental difficulties encountered with this very reactive metal.

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

Element	Rockwell Data	Johnson and Yonco ⁽⁴¹⁾
Y	3×10^{-7}	-
La	4×10^{-10}	5×10^{-10}
Ce	5×10^{-10}	14×10^{-10}
Nd	7×10^{-9}	-
Pr	2×10^{-9}	3×10^{-9}
Gd	4×10^{-8}	-

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

2.2.2 Actinide Electrochemical Data

A system to acquire electrochemical data for the actinides was set up in a hot laboratory at Rockwell's Santa Susana Field Laboratory. Photos of this installation are given in Figures 1 and 2.

After repairing leaks and certifying that the glove box met leak rate criteria, the argon atmosphere was established in the glove box. An oxygen content of approximately 1 ppm was obtained using the vacuum atmosphere DRITRAIN and NITRAIN equipment (Figure 2).

While Rockwell was awaiting DOE permission to start up the test pending DOE review of the NEPA Action Description Memorandum, Rockwell Management concluded it would be impractical to continue the TRUMP-S project beyond Stage 1 activities at the Santa Susana Field Laboratories. As a result, an effort was undertaken to locate a facility where the TRUMP-S actinide tests could be conducted for both Stage 1 and Stage 2.

2.3 PROGRAM SUMMARY

The TRUMP-S process is feasible and cost-effective, but additional electrochemical data is required to determine actinide separation efficiency and product purity.

The rare earth electrochemical data has been obtained and is summarized in this report. The experimental chloride-free energies of formation were measured along with activity coefficients of the chloride and metal in LiCl-KCl electrolyte and cadmium solvents. Activity coefficients will be very important in obtaining good separation of actinides from rare earths. Preliminary separation tests indicate that additional separation studies are required to obtain the required 99% actinide removal in the product containing greater than 90% actinides. Calculated distribution coefficients using Rockwell electrochemical data have similar slopes with experimental data, but the absolute values differ somewhat. The cause of this discrepancy is being investigated.

Figure 1. TRUMP-S Actinide System

Figure 2. TRUMP-S Glove Box Viewed from Control Gallery

TASK 3. PARTITIONING-TRANSMUTATION REVIEW

3.1 OBJECTIVE

Develop a position paper on the feasibility of partitioning and transmutation (P-T) of long-lived isotopes (actinides and selected fission products) in nuclear wastes produced by the U.S. civilian nuclear power program.

3.2 ACCOMPLISHMENTS

A report, Nuclear Waste Management with Actinide Conversion (Reference 3), was completed in September 1989 documenting the conclusions of a review and evaluation of P-T technologies. The report includes the following topics:

- Historical background on the development of P-T technologies
- Nuclear waste management scenarios with actinide conversion, including P-T schemes, and a proposed strategy for nuclear waste management
- LMR transmutation process, employing either a large number of Advance Liquid Metal Reactors (ALMRs), each burning fuel with a small actinide percentage, or a few Minor Actinide Conversion Reactors (MACRs) burning fuel consisting entirely of minor actinides
- Feasibility of transmuting fission products, including identification of the problem isotopes
- Transmutation processes in the Light Water Reactor (LWR)
- Arguments for P-T, focusing on the aspects of risk reduction and cost savings.

The conclusion of the report is that there is a significant potential economic benefit resulting for the utilization of a nuclear waste management system with P-T, compared to the direct disposal of spent fuel. The risk savings with P-T would be worth at least \$2.36 billion/yr for 100 GW(e) generating capacity. Assuming that the existing U.S. LWR generating capacity of 100 GW(e) has an effective lifetime of 40 yr, the risk cost savings that would result with P-T totals 40 times \$2.36 billion or \$94.4 billion. The additional repository cost savings with greater confinement disposal is estimated at about \$8.37 billion. Therefore, a total benefit of about \$100 billion could be realized in about 40 yr through the introduction of P-T. Any expansion of nuclear power would increase this benefit further. It is estimated that the cost to develop and implement P-T will be significantly less than this amount.

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