that the constant-background method gives results for ℓ/β in regions I and II that differ by almost 6%, whereas those obtained by the time-dependent method agree within the experimental error. For channel numbers greater than 182, the delayed-neutron correction ranges from 60 to 90% of the total signal so that the results are very sensitive to errors in $n_D(t)$; this region is therefore excluded from the analysis, as would normally be the case.

C. Sastre
E. V. Weinstock

Brookhaven National Laboratory
Upton, New York

Received March 20, 1964
Revised July 6, 1964

ACKNOWLEDGMENTS

We are grateful to Walter Kley, who assisted us in the taking of the data and the interpretation of the results, and to Joan Felberbaum, who wrote the Fortran program used in the analysis of the data.

Synergism in the Solvent Extraction of Alkali Metals*

Solvent extraction studies of the removal of fission products from nuclear fuel reprocessing wastes are under intensive study in many laboratories. Removal of strontium-90, cerium-144, promethium-147, and cesium-137 from process waste is of particular interest because of the long half-lives, intense heat generating rates and the biological hazards of these isotopes. Interest in recovery of these materials is also prompted by their potential uses as radiation and heat sources. Waste solutions from which separation of the above isotopes is normally to be effected are usually acidic and contain high concentrations of sodium, iron, and other non-radioactive isotopes. It has therefore been imperative to find an extraction technique which will remove these fission products from acid solutions with large separation factors.

Processes which extract strontium and the rare earths, but not cesium, from acidic solutions with di(2-ethylhexyl)phosphoric acid (D2EHPA) in kerosene have been developed at the Hanford Laboratories[1] and at the Oak Ridge National Laboratory[2].

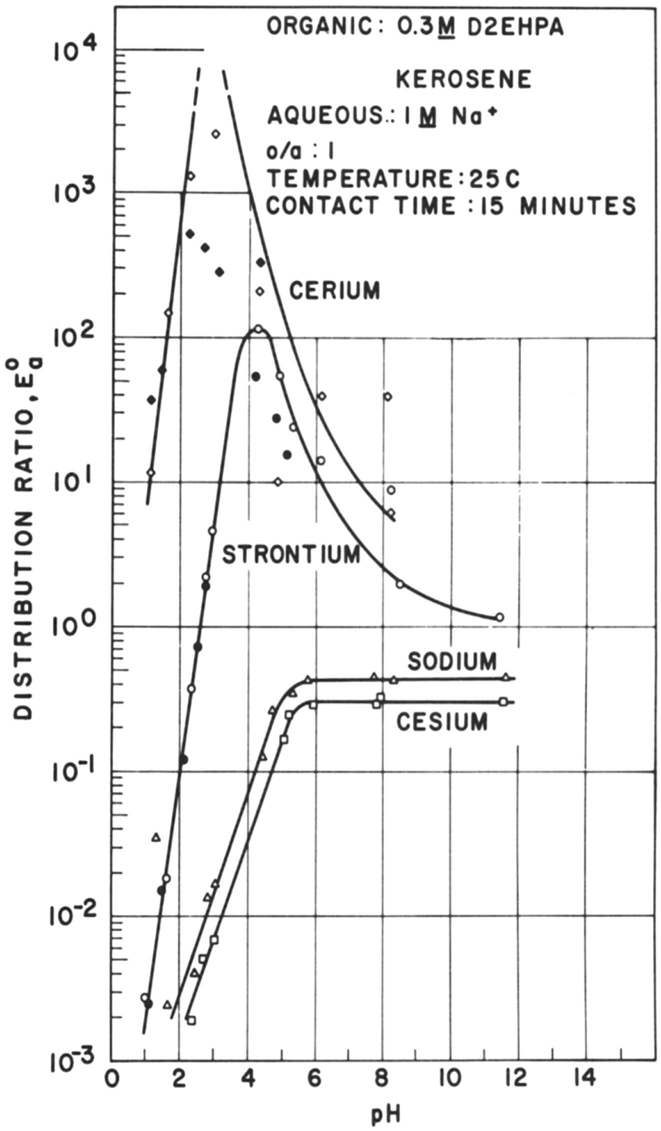

Fig. 1. D2EHPA extraction as a function of pH (open points indicate the organic contained 0.15M TBP to prevent third phase formation).

Cesium extraction has been a more difficult problem. Only moderate success was achieved in earlier work in which cesium was extracted from near neutral or alkaline solutions into high dielectric constant solutions as the dipicrylaminate, polybromide, or the polyiodide[1,3,4]. Recently,

---

*Work performed under Contract No. AT(45-1)-1350 for the USAEC.

[1] R. E. BURNS, W. W. SCHULZ and L. A. BRAY, "Recent Solvent Extraction Studies at Hanford Laboratories," *Nucl. Sci. Eng.* **17**, 566-575, (December, 1963).

[2] D. E. HORNER, D. J. CROUSE, K. B. BROWN and B. WEAVER, "Fission Product Recovery from Waste Solutions by Solvent Extraction," *Nucl. Sci. Eng.* **17**, 234-246, (October, 1963).

[3] LOUIS M. SLATER, "Extraction of Sodium and Cesium Polyiodides into Nitrobenzene," *Nucl. Sci. Eng.* **17**, 576-585, (December, 1963).

[4] F. C. W. PUMMERY and J. H. MOSS, "The Solvent Extraction of Cesium by the Poly-Bromide Method from Mock Windscale Highly Active Wastes," AERE-R-3596, Harwell, (December, 1960).

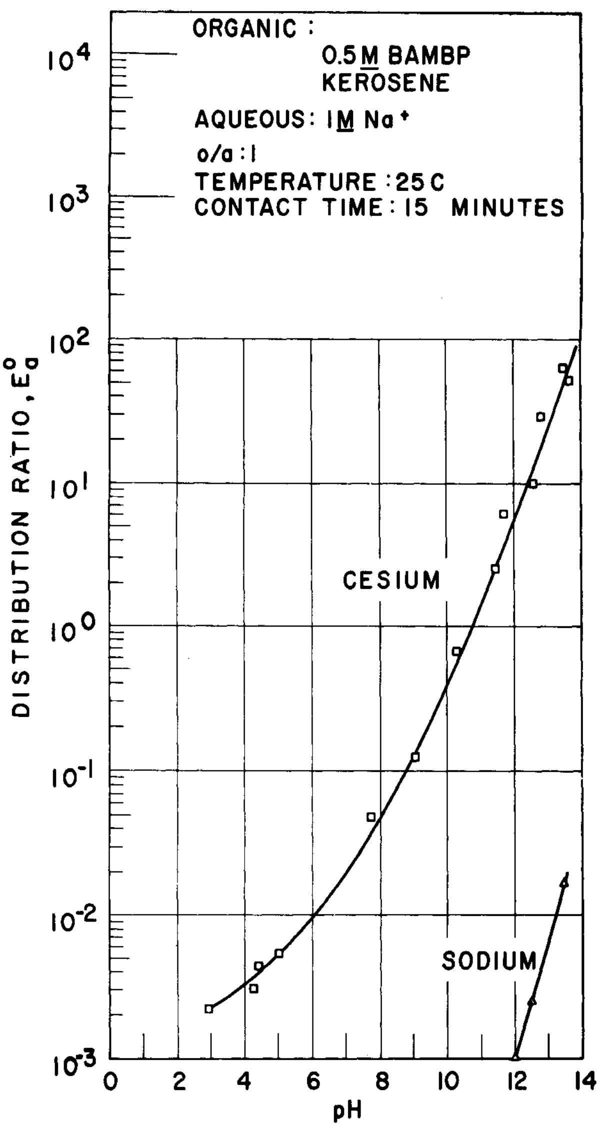

Fig. 2. BAMBP extraction as a function of pH.

workers at ORNL have surveyed a large number of possible cesium extractants and have found that high-molecular-weight phenols, particularly 4-sec-butyl-2-(α-methylbenzyl) phenol (BAMBP), are good extractants for cesium from highly basic solutions and have a relative affinity for alkali metals of $Cs > Rb > K > Na > Li$[5].

In this note, we wish to describe an interesting effect that we have recently discovered[6], that affords good separation of strontium, the rare earths, and cesium by simultaneous extraction from acidic solutions. As shown in Fig. 1, D2EHPA will extract strontium and cerium with large separation factors, but not cesium, from weakly acidic solutions. In this system, the relative affinity for the alkali metals is $Cs < Rb < K < Na < Li$[7]. Figure 2 shows that BAMBP will effectively extract cesium from solution at pH values above 10. It was therefore of interest to find that a mixture

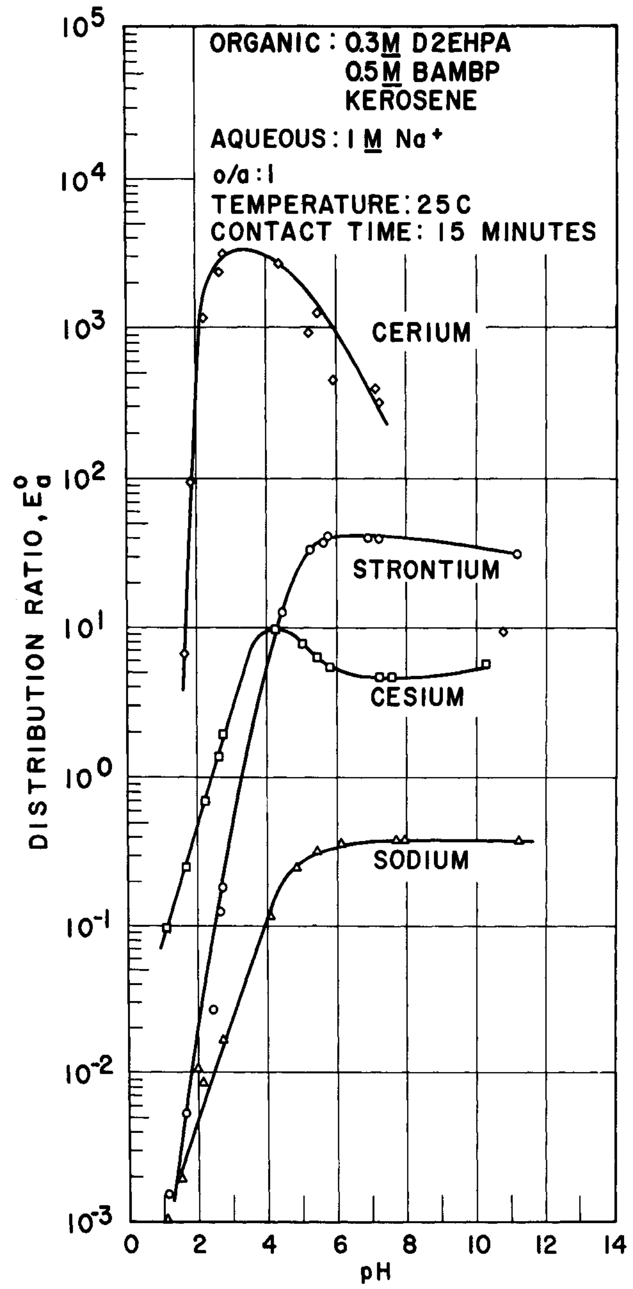

Fig. 3. BAMBP-D2EHPA extraction as a function of pH.

---

[5] "Chemical Technology Division Annual Progress Report for Period Ending May 31, 1963," Oak Ridge National Laboratory, ORNL 3452, p. 175.

[6] L. A. BRAY, "Solvent Extraction Process for Recovery of Strontium, Rare Earths, and Cesium from Radioactive Waste Solutions," presented at the Northwest Regional Meeting of the American Chemical Society, Bellingham, Washington, (June 17, 1963).

[7] "Chemical Technology Division Annual Progress Report for Period Ending June 30, 1962," Oak Ridge National Laboratory, ORNL-3314, p. 112.

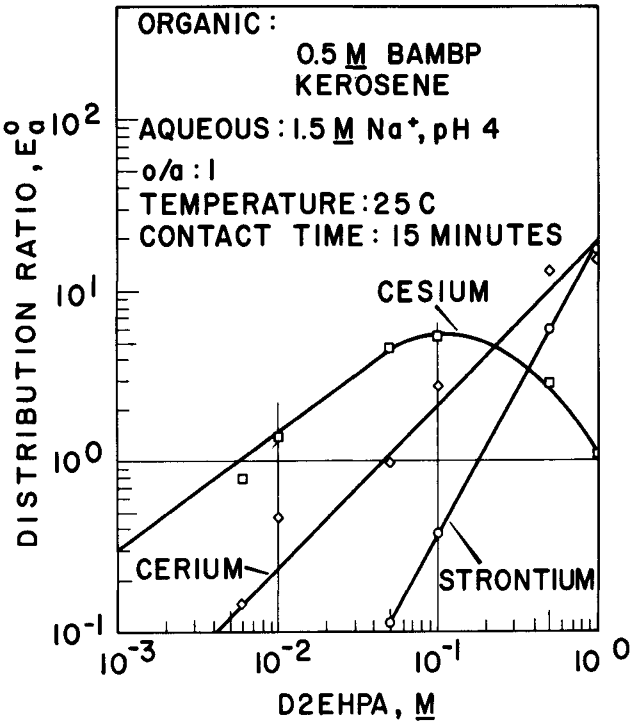

Fig. 4. Distribution as a function of D2EHPA concentration.

of these dissimilar extractants will coextract not only strontium and cerium, but also cesium from acidic solutions. Figure 3 shows that a synergistic effect takes place in the mixed BAMBP-alkyl phosphate system, broadening the range of effective cesium extraction to pH 2-14, with a 30-fold increase in cesium distribution occurring at pH 4.5.

Figure 4 shows the effect of varying the concentration of D2EHPA at a constant BAMBP concentration on the distribution of strontium, cesium, and cerium at an equilibrium pH of four. The maximum cesium distribution occurs at a ratio of BAMBP to D2EHPA of approximately five.

It has also been found that the phenol-alkyl phosphate-synergistic effect is not restricted to BAMBP and D2EHPA, but that many other phenols and acid-phosphates exhibit a similar effect. The mechanism of this marked change in extraction behavior is under investigation and will be reported in a subsequent communication[8].

L. A. Bray

Hanford Laboratories
General Electric Company
Richland, Washington

Received April 27, 1964
Revised June 22, 1964

---

[8] W. E. KEDER, L. A. BRAY and E. C. MARTIN, *The Mechanism of Solvent Extraction of the Alkali Metal Ions*, (to be published).