Cat 15

BNWL-1256
UC-23

[redacted]

PACIFIC NORTHWEST LABORATORY
DIVISION OF ISOTOPE
DEVELOPMENT PROGRAMS
QUARTERLY REPORT: AUGUST - OCTOBER 1969

November 1969

[redacted]

AEC RESEARCH & DEVELOPMENT REPORT

BNWL-1256

BATTELLE NORTHWEST
BATTELLE MEMORIAL INSTITUTE PACIFIC NORTHWEST LABORATORIES
BATTELLE BOULEVARD, P. O. BOX 999, RICHLAND, WASHINGTON 99352

LEGAL NOTICE

PACIFIC NORTHWEST LABORATORY
RICHLAND, WASHINGTON
operated by
BATTELLE MEMORIAL INSTITUTE
for the
UNITED STATES ATOMIC ENERGY COMMISSION UNDER CONTRACT AT(45-1)-1830

AEC-RL RICHLAND, WASH.

BNWL-1256

UC-23, Radioisotope and
Radiation Applications

PACIFIC NORTHWEST LABORATORY
DIVISION OF ISOTOPE DEVELOPMENT PROGRAMS
QUARTERLY REPORT: AUGUST - OCTOBER 1969

Edited by W. F. Sheely

November 1969

BATTELLE MEMORIAL INSTITUTE
PACIFIC NORTHWEST LABORATORIES
RICHLAND, WASHINGTON 99352

Printed in the United States of America
Available from
Clearinghouse for Federal Scientific and Technical Information
National Bureau of Standards, U.S. Department of Commerce
Springfield, Virginia 22151
Price: Printed Copy $3.00; Microfiche $0.65

DIVISION OF ISOTOPE DEVELOPMENT PROGRAMS QUARTERLY REPORT: AUGUST - OCTOBER 1969

ABSTRACT

PROMETHIUM COMPATIBILITY

The promethium compatibility work is being conducted on schedule. The experimental evaluation of the compatibility samples is nearing completion and work has been initiated on a final report summarizing the entire promethium compatibility program.

ENCAPSULATED WASTE MANAGEMENT CESIUM AS A PROCESS RADIATION SOURCE

Assessment of industrial interest in waste management-encapsulated cesium is proceeding. A study has been made of the possibility of producing 5 MCi of en'capsulated cesium sources in the next 18 to 22 mo. A preliminary estimate indicates that the requirement could be met either by processing at PNL or by shipping to ORNL.

RADIATION CHARACTERISTICS OF FISSION PRODUCT RHODIUM AND PALLADIUM

Experimental work is being directed to the measurement of the half life of ^{102m}Rh

NONDESTRUCTIVE TESTING TECHNIQUES

NDT for Irradiation Sources

Detailed circuit design for the multi-element transducer concept is continuing. The scan logic, gates, preamplifier, and readout circuitry are undergoing development at the present time. No major obstacles have been encountered to date.

Neutron Radiography with ^{252}Cf

In the development of a thermal neutron radiography camera, a boron carbide/epoxy resin compound was found to be the most

effective neutron shield of the candidate materials evaluated. A basic camera design for the camera has been formulated and a prototype constructed. After the camera has been tested and evaluated, its applicability to a number of classes of problems will be studied.

ADVANCED ALPHA SOURCE DEVELOPMENT

Sputtering parameters have been investigated using cold materials in preparation for sputter-depositing and sputter-coating alpha sources.

EVALUATION OF ISOTOPE PRODUCTION IN POWER REACTORS

Comparison has been made of the relative costs of ^{238}Pu produced by Np target irradiation in power reactors or in high flux reactors. The calculations indicate that neutron flux and neutron spectrum have very little influence on ^{238}Pu production costs within the limits investigated.

A survey of potential reactor fuel reprocessors indicated that substantial neptunium recovery facilities will be available in the near future. A year-by-year estimate of neptunium availability from power reactors was made.

RADIATION CHARACTERISTICS OF CIRCULATORY SUPPORT ISOTOPIC HEAT SOURCES

Neutron fluence and doses were calculated at axial and radial positions from a ^{238}Pu source in a right circular tissue-equivalent phantom.

Photon dose-rate profiles have been completed for the LASL-I source in tissue fluid. Also, total dose rates have been measured on the surface of the Remab phantom.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

PACIFIC NORTHWEST LABORATORY
DIVISION OF ISOTOPE DEVELOPMENT PROGRAMS
QUARTERLY REPORT: AUGUST - OCTOBER 1969

Edited by W. F. Sheely

INTRODUCTION

This is the twelfth report of a series initiated in 1966 to provide detailed and timely information on the results of the isotopic fuels program and related research being conducted at the Pacific Northwest Laboratory by Battelle-Northwest for the U.S. Atomic Energy Commission. The previous reports of the series are BNWL-385, 466, 570, 680, 681, 781, 877, 924, 1010, 1085, and 1177.

This report covers the 3-mo period, August 1969 through October 1969.

PROMETHIUM COMPATIBILITY

H. T. Fullam and J. H. Jarrett

The experimental work for the $^{147}Pm_2O_3$ compatibility program is nearly completed. Work is underway on the final report summarizing the entire $^{147}Pm_2O_3$ compatibility program. The heating of samarium metal (stand-in for promethium metal)-containment material test capsules was continued on schedule.

The final experimental test (18-mo - 1100 °C - $^{147}Pm_2O_3$) of the oxide compatibility series was completed at the end of August, 1969. Metallographic examination of the containment materials is in progress. Work leading to the electron beam microprobe analysis of the $^{147}Pm_2O_3$ compatibility with capsule materials was started. Select metallography samples of the capsule sections, 12-mo - 1100 °C - $^{147}Pm_2O_3$, that were photographed in June, 1969, will be used for the initial microprobe work. The samples were decontaminated to a large extent in an ultrasonic cleaner using water as a solvent. They were dried, placed face down on clean paper, and the bottoms and sides sprayed with a vinyl paint to fix the remaining contamination. Smearable contamination was found only on the sample faces. The samples were individually wrapped in Kleenex and sealed in plastic bags. Examination of samples after several days storage revealed no spread of contamination from the sample face to the bottom or side. Next, a layer of carbon was vapor deposited onto the metallography sample faces. The purpose of this layer was to provide a conductive sample surface necessary for the microprobe analysis and to tie down contamination on the sample face. The amount of smearable contamination on the sample face was reduced, but not eliminated. For the microprobe analysis, a layer of conductive tape will be used in addition to the carbon layer to minimize the smearable contamination on the sample face, thus minimizing the contamination of the microprobe system.

The report "Cold Pressing of Aluminum - Rare Earth Oxide Composites," BNWL-1014 by H. T. Fullam, was issued.

ENCAPSULATED WASTE MANAGEMENT CESIUM AS A PROCESS RADIATION SOURCE

H. H. Van Tuyl

As mentioned in the recently issued report[1] on the use of Hanford waste management cesium products as radiation sources, several prospective users have indicated an interest in obtaining low cost cesium. Since the report was issued, discussions have been held with a representative of industry relating to interim cesium production capabilities and long-range plans for the Hanford Waste Management Program. The organization represented in the discussion is evaluating the prospects for industrial participation in production of cesium radiation sources.

The report[1] also indicated that prospective radiation source users were interested in the incremental cost associated with delivering the cesium chloride in containers other than the 2 114-in. OD × 23.9-in. containers now projected by the Hanford Waste Management Program.[2] From the source users' standpoint, a smaller source, about 1-in. OD × 18-in., would be desirable if it could be obtained at a reasonable cost. Cost analysis has been initiated in this area.

At the request of DID, a brief study was made of the possibility of producing 5 MCi of encapsulated cesium sources during the next 18 to 22 mo. The sources should be about 1-in. diameter by 12 to 18-in. long. They should be encapsulated in stainless steel of the minimum thickness required to assure safe containment and should contain void volume sufficient to assure safety on accidental overheating.

Cesium is available from ARHCO as a crude containing about a 6:1 mole ratio of Na:Cs. Their purification equipment is not properly sized to permit concentration to the required high purity. They might be able to provide a high purity cesium by

using the HAPO shipping cask as the final purification system. ARHCO can ship the crude cesium to PNL as liquid, and beginning about November 15, 1969, they will be able to ship cesium to ORNL in about 500 kCi batches in the modified HAPO cask. The shipments to ORNL would be purified cesium, using the cask as the final purification system. Cask shipments would require about 1 week each at PNL and ORNL plus 1 week transit time each way. Thus, one shipment per month will be possible.

Processing at PNL would require final purification in ion exchange equipment, conversion to the chloride in melt-casting equipment, loading into containers, and welding. Essentially all of the required development work has been done on the process steps involved, but the process has not been demonstrated with fully radioactive feed.

A detailed cost estimate would include consideration of acquisition, shipping, purification, and encapsulation costs. The overall cost estimate will depend on whether the estimate is based on fuel cost recovery or on an arbitrary charge for the cesium.

ORNL could receive enough cesium from ARHCO to satisfy the requirements in the allotted time. Therefore, since it appears that either PNL or ORNL could satisfy the requirements for cesium, a detailed estimate seems to be appropriate at both sites.

References

1. *H. H. Van Tuyl, H. T. Fullam, and L. K. Mudge. Unpublished Data. Battelle-Northwest, Richland, Washington, July 1969. (Preliminary Data: Low-Cost Cesium Radiation Sources from Hanford Waste Management Program)*

2. *J. R. LaRiviere, D. C. Nelson, M. L. Oldfather, and R. C. Roal, Facilities Design Description Strontium and Cesium Encapsulation and Storage Facilities, Rough Draft Issue, ARH-1264, Atlantic Richfield Hanford Company, Richland, Washington, August, 2969.*

RADIATION CHARACTERISTICS OF FISSION PRODUCT RHODIUM AND PALLADIUM

The study to determine the nature and amounts of radioactivity associated with rhodium and palladium produced in power reactors was continued during the period of this report. An interim report was prepared and distributed describing the results of the study for Fiscal Year 1969.

Currently the effort is directed at measurement of the half-life of ^{102m}Rh. Samples of well-aged rhodium from the Hanford reactors have been prepared by extensive purification to remove traces of radioactive impurities. These samples sealed in glass vials are being counted weekly using a Li-drifted germanium diode. It is anticipated that sufficient data points will have been accumulated by the end of Fiscal Year 1970 to give a half-life value within 10% of the true value.

NONDESTRUCTIVE TESTING

NDT FOR IRRADIATION SOURCES

R. W. Steffens

NDT methods and device development continued with the design of electronic circuits for practical implementation of the multi-element ultrasonic transducer concept described in previous reports. The most recently fabricated transducers had 32 elements in 0.6-in. and 32 elements in 1.0-in. These transducers were evaluated and homogeneous ultrasound detection characteristics were observed among the individual elements and the defect detection sensitivity increased as the number of elements per inch decreased. Thus, the multi-element transducer fabrication methods are adequate for production of the high quality transducers required for practical use of the multi-element transducer concept.

The instrument under development for implementation of the multi-element ultrasonic transducer is outlined in the Figure 5.1 block diagram. The scan logic, gates, preamplifier, and readout preparation blocks are unique to the multi-element concept, and development is being concentrated in these circuits. The scan logic sequentially provides 32 individual gate pedestals for gate activation. The scan logic is fully developed and functional, although less than optimum gates have been fabricated. Gate operation is adequate for system evaluation. However, more refined gates must be developed if the full capabilities of the multi-element concept is to be realized. A high input-impedance, low-noise preamplifier has been designed. This amplifier provides an efficient load for the transducer gates and thus enhances the system sensitivity. The readout preparation circuitry is dependent upon the results obtained with the above circuits, and thus, design will not be initiated until the design of those circuits are complete.

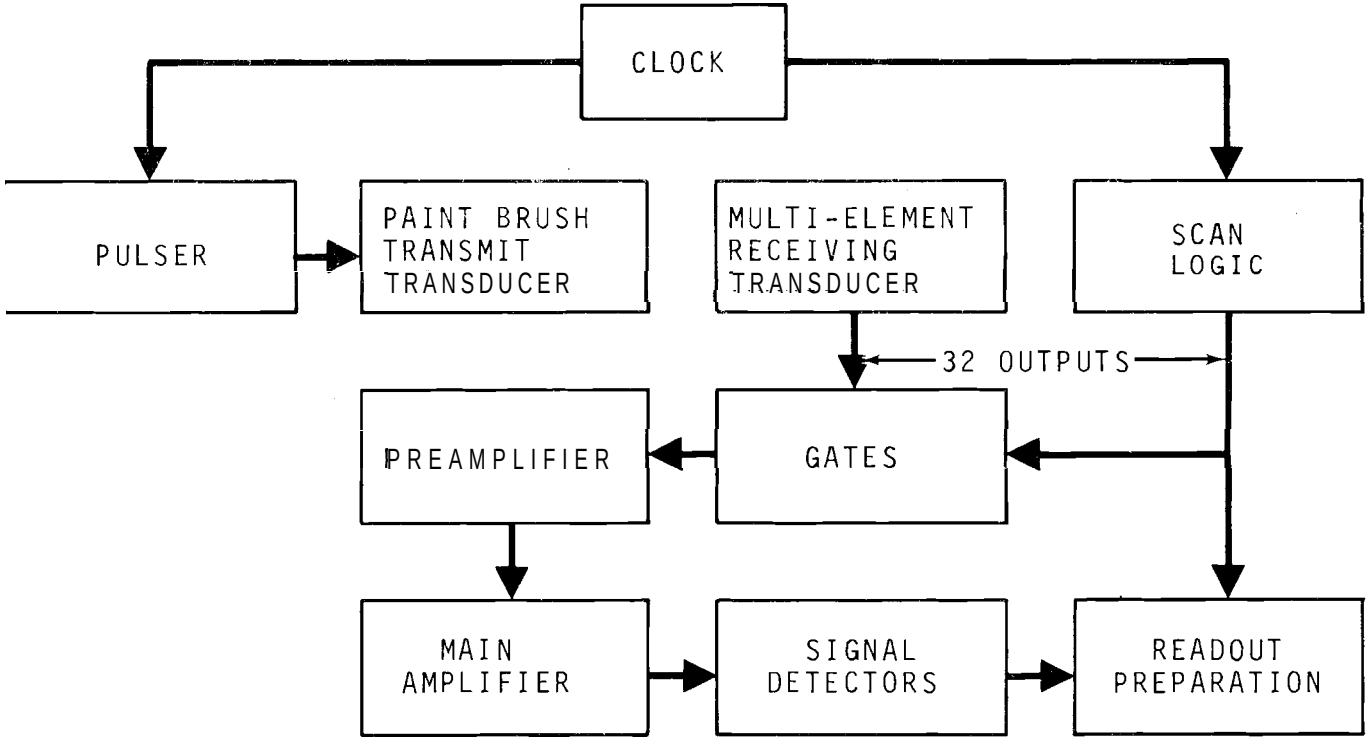


FIGURE 5.1. Block Diagram of Multi-Element Ultrasonic Transducer Test Instrument

A solid-state pulser compatible with the 5 MHz paint brush transmit transducer has been designed. This pulser uses an SCR as the active element. The UT-40 ultrasonic test station is presently being used for the main amplifier and detection circuitry. Modifications of the UT-40 detection circuitry will eventually be incorporated into the multi-element instrument to make the instrument self contained. It should be noted that most of the above ultrasonic test circuitry under development or modification is applicable to ultrasonic testing of isotope containment capsules in general.

NEUTRON RADIOGRAPHY WITH ^{252}Cf

J. L. Cason

A research program in neutron radiography is being conducted to determine the usefulness of ^{252}Cf as a thermal neutron radiographic source. Our previous experimental evaluation demonstrated the feasibility of using ^{252}Cf as a source for neutron radiography. Presently, a more comprehensive evaluation is underway. The study includes experimental verification of metal hydrides for use as high efficiency moderators. The results will include thermal flux measurements and radiographic resolution and imaging studies.

An evaluation to determine the optimum geometry and material for shielding ^{252}Cf was performed; the results led to design criteria for a first generation, portable neutron camera. The materials evaluated were ZrH_2, TiH_2, CH_2, GdO_2, Cd, and a boron carbide/epoxy resin compound.

The boron carbide/epoxy resin compound (B/E) offered the best fast neutron shield. The reasons for the high efficiency shielding characteristics are:

- The neutrons are moderated by the high level of H and C in the epoxy resin.

a Simultaneous to moderation, the boron provides a large capture cross-section at the lower neutron energy.

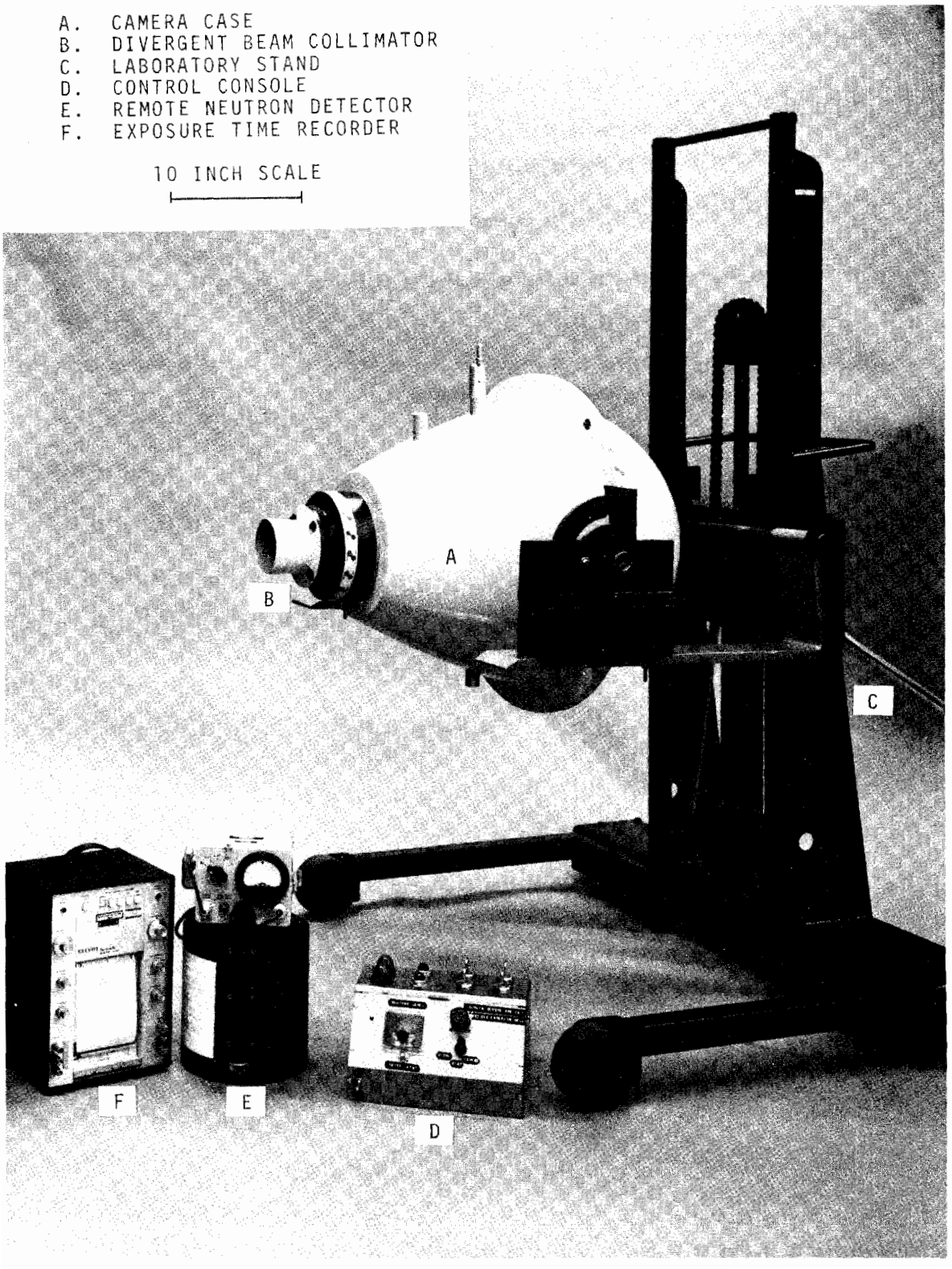
A half-value for fast neutrons of ^{252}Cf for the B/E was found to be about 1 in.

With a combination of the characteristics of the experimental camera (i.e., variable moderation and collimation) and the evaluation of shielding material, a basic design was outlined for a first generation portable neutron camera. A photograph of this camera mounted on its laboratory stand appears as Figure 5.2. The camera (NC-1) provides complete radiation protection for the neutron source when in the STORE node. In the OPERATE mode, the camera provides a beam of thermal neutrons (>10^6 nv) in only one direction. Elsewhere, sufficient shielding would permit the operator to remain behind the camera during operation. Exposure times for producing a neutron radiograph range from 1 min to 2 hr, depending upon technique and sample. An internal device allows one to adjust the moderator material and thickness, thus tailoring the neutron spectra for a given situation. The collimator is adjustable in length and divergent angle.

NC-1 is constructed of a special 1/2-in. fiberglass laminate with a high strength-to-weight ratio. Actual shell weight is about 30 lb. The camera is extremely versatile because the shell is strong, lightweight, and fireproof; thus, it is suitable for both field and laboratory use. In addition, two shells with identical characteristics to the one shown in Figure 5.2 were constructed. One of these shells will be destructively tested and the other used as a mock-up assembly for evaluating future design changes.

At present, applications for neutron radiography with ^{252}Cf that we have evaluated and termed feasible are:

a Isotope Development; e.g., encapsulated radioactive isotopes (^{60}Co).



Neg 0694559-1

FIGURE 5.2. Neutron Radiography Camera NC-1

- a Forensic Science; e.g., ammunition assay, narcotics detection.
- a Reactor Development and Technology; e.g., simulated reactor fuel pins.

With the aid of NC-1, many more applications will be evaluated.

Tests will also be conducted to determine optimum thermal to fast ratios most desirable for a given material combination. Anti-scatter grids are under consideration which make neutron radiography of thick objects more desirable. A real-time imaging system is being prepared for evaluation with NC-1.

Topical Reports in Progress - October 1969

- a New shielding materials and techniques for ^{252}Cf.
- a Lightweight containment vessels for shipping and storage of high flux neutron sources (e.g., ^{252}Cf).
- Variable divergent collimation with ^{252}Cf for neutron radiography.
- Charts and data for general use:
  Moderation of ^{252}Cf with metal hydrides.

Papers - Presentations

- a ANS - paper accepted for winter meeting - San Francisco, "Neutron Radiography with ^{252}Cf."
- a Forensic Science Symposium - October 28-30, 1969, Washington, D.C., "Neutron Radiography with ^{252}Cf in Forensic Science."
- a ASNT - March meeting 1970, abstract submitted, "Thermal Neutron Radiography with ^{252}Cf."

ADVANCED ALPHA SOURCE DEVELOPMENT

J. E. Hansen

Work in this area is being divided into four technical areas:

- Determination of substrate criteria for optimum deposit-substrate bonding.
- Determination of window deposit fabrication parameters for optimum deposit bonding and integrity.
- Determination of preferred techniques for depositing the isotope source material on the substrate.
- Theoretical analyses to determine preferred material types and structures for specific applications to provide conceptual source designs offering maximum isotope containment, and to provide a continuing basis for experimentation.

Work is proceeding in all of these technical areas.

Evaluation of the deposit-substrate bonding relationship has included tensile, thermal, bend, and fatigue testing. Test conditions are listed in Table 6.1. Examination of sources subjected to testing has been by dye penetrant and microscopic means. In all cases, except in bend testing of Si deposits, the deposits were found to be free of cracks, porosity, or unbonding before and after testing. Investigation of the deposit-substrate bonding relationship has verified that the rf-sputtering process is capable of providing a very good bond between deposit and substrate. This bond requires a clean substrate for the deposit. However, substrate surface finish does not appear to substantially effect bonding strength. Evaluation of bond strength for substrate surface finishes varying from polished to sintered surfaces has shown good bonding is attainable in all cases. These conclusions are experimentally limited to the deposit materials tested, Cu and Si.

TABLE 6.1. Tests Used to Evaluate Deposit-Substrate Bonding

Test	Conditions	Results
Tensile	750-1000 psi	No failure of deposit (epoxy failed first)
Bend	180° bending over 1/2-in. mandrel	No failure of Cu deposits, unbonding occurred with Si deposits
Fatigue	16 million cycles over 0.225-in. deflection	No failure of Si or Cu deposits
Thermal	A. 1 hr at 750 °F, 35 min at 300 °F, quenching to 32 °F, quenching to -70 °F	No failure of Si or Cu deposits
	B. 5 cycles directly between 750 °F and -70 °F	No failure of Si or Cu deposits

Sputtering process parameters have been determined for deposition of Cu and Si. Deposition parameters for Si are listed in Table 6.2. Values for Cu are under evaluation.

TABLE 6.2. Deposition Parameters for Si

Power, W	Time, Hr	Bias	Maximum Coating Thickness Microns
800	2.0	90/10	3.6
800	2.0	85/15	2.8
800	3.0	90/10	4.7
500	2.0	90/10	2.8
800	2.0	96/4	3.3

Three different methods of fixing the isotope compound on the substrate are to be evaluated. These methods are described below:

- The $^{241}AmO_2$ will be prepressed into a wafer geometry and will then be final-pressed into an integral Cu substrate

which will leave only one surface of the isotope wafer exposed. This compact will be sintered, and a thin Cu window will be deposited over the complete substrate-isotope surface.

- The second concept is the same as the first except a $^{241}AmO_2$-Cu cermet mixture will be used for the active portion of the source instead of 100% $^{241}AmO_2$. The dispersion of Cu throughout the isotope will provide areas for enhanced metallurgical bonding 'between deposited window and the substrate.
- The third concept will entail deposition, by rf-sputtering, of a $^{241}AmO_2$-Cu film on a Cu substrate. This mixed film will then be covered by a pure Cu film. This method will result in a nearly atomic mixture of isotope and Cu matrix which should provide very good source integrity. This concept requires fabrication of an AmO_2-Cu cermet target for sputtering.

Fabrication of prototype $^{241}AmO_2$ alpha sources is awaiting installation of the rf-sputtering system in a glovebox. At this time, the glovebox is installed and final connection and testing of the sputtering system is being performed. The facility is expected to be operational in October.

Work prior to this time has been performed in "cold" facilities, and Sm_2O_3 and UO_2 have been used as stand-ins for AmO_2. In addition to preparation of Si and Cu deposits on Cu and SS substrates, many simulated isotopes containing substrates have been prepared. Figure 6.1 depicts several UO_2-containing Cu substrates with the UO_2-Cu cermet ratio varying from 100% UO_2 to 33% UO_2, 67% Cu.

Cermet tiles have also been prepared for use as a sputtering target. Figure 6.2 depicts 16 one-in. tiles of UO_2-Cu cermet formed in a target array. These tiles simulate a $^{241}AmO_2$ target containing approximately 45 Ci/cm^2 activity.

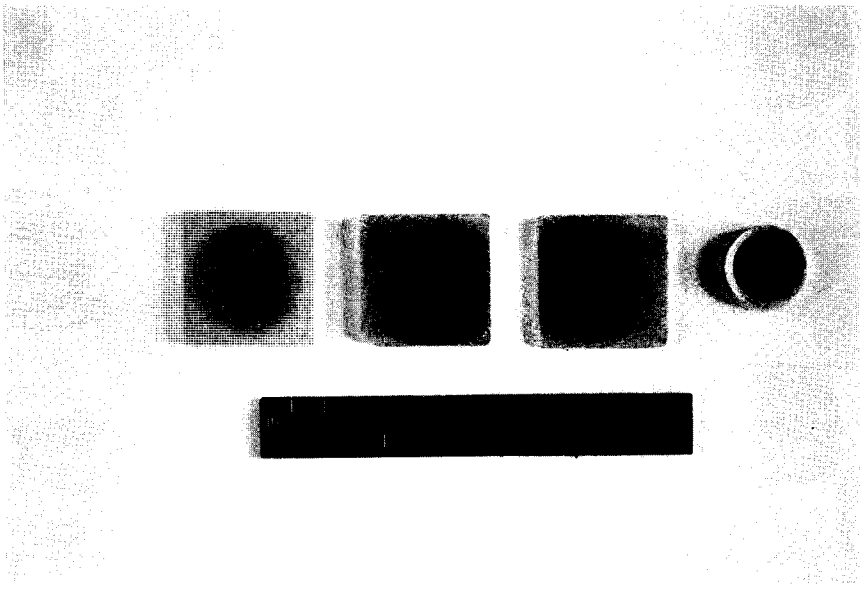


FIGURE 6.1. UO_2-*Cu Substrates*

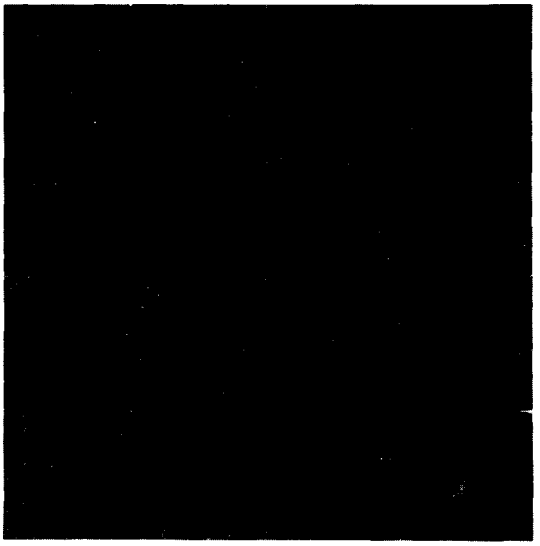


FIGURE 6.2. UO_2-*Cu Cermet Tiles for Sputtering Target*

EVALUATION OF ISOTOPE PRODUCTION IN POWER REACTORS

R. W. McKee and S. E. Nunn

PLUTONIUM-238 COST STUDIES - THE EFFECT OF NEUTRON FLUX AND COST

Calculations have been carried out to compare the relative costs of ^{238}Pu produced by neptunium target irradiation in power reactors with costs of ^{238}Pu produced by neptunium target irradiation in high flux reactors. The TAIRCOST program, which optimizes costs with respect to irradiation time, was used for the cost calculations. The target irradiation yield data were obtained using the BURN program. In general, high flux reactors have a softer neutron spectrum than power reactors, and this characteristic was approximated by reducing the spectral index (Westcott r) at the higher fluxes. Costs were calculated for three different reactors having the following characteristics:

- Flux = 2.5×10^{13} n/cm^2-sec and Westcott r = 0.2 (power reactor).
- Flux = 5×10^{13} n/cm^2-sec and Westcott r = 0.1.
- Flux = 1×10^{14} n/cm^2-sec and Westcott r = 0.05.

As in previous comparisons, two processing cost sets were used to represent the maximum and minimum costs one would expect for this type of irradiations. The important parameters for these two cost sets are shown in Table 7.1. The cost of neutrons would be quite different in a high flux reactor compared to a power reactor, and this cost was examined as a variable.

Figure 7.1 shows the effect of increasing neutron cost on the cost of producing ^{238}Pu when neptunium is valued at $100/g. In all cases there is an increase in the cost of ^{238}Pu as neutron cost increases, but not in proportion to the neutron cost. For example, a tenfold increase in neutron cost from $1,000/g to $10,000/g increases ^{238}Pu cost on the order of 20%.

TABLE 7.1. Base Cost Sets

	Low Processing Costs	High Processing Costs
Inventory Charge, %/yr	10	10
Encapsulation and Reprocessing Losses, % each	2	2
Reprocessing Cost, $/kg	2,000	15,000
Reprocessing Time, mo	4	4
Density of ^{237}Np, g/cm^3	0.2	0.2
Fabrication Cost, $/kg	3,040	19,000

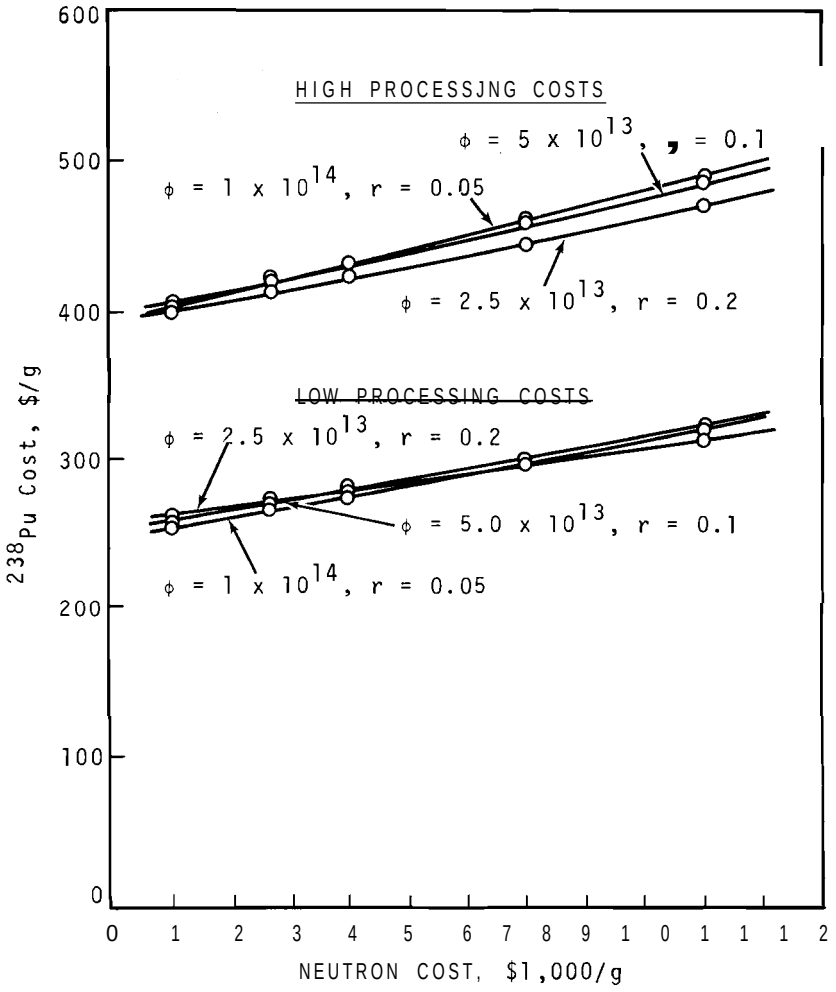


FIGURE 7.1. Effect of Neutron Cost on the Cost of Producing ^{238}Pu with Neptunium Valued at $100/g

Additional calculations were made using neptunium values of $50/g and $25/g with similar results. The results for all three neptunium values are shown in Figures 7.2, 7.3, 7.4, and 7.5 as plots of ^{238}Pu cost versus neutron flux. The low processing cost cases are shown in Figures 7.2 and 7.3 for neutron costs of $2,700/g and $10,000/g, respectively, and the high processing cost cases are shown in Figures 7.4 and 7.5, also for neutron costs of $2,700/g and $10,000/g, respectively. These plots illustrate an insensitivity of ^{238}Pu costs to neutron flux where cost inputs are fixed, but the lowest costs tend to be at the lower flux levels, especially with the high processing costs.

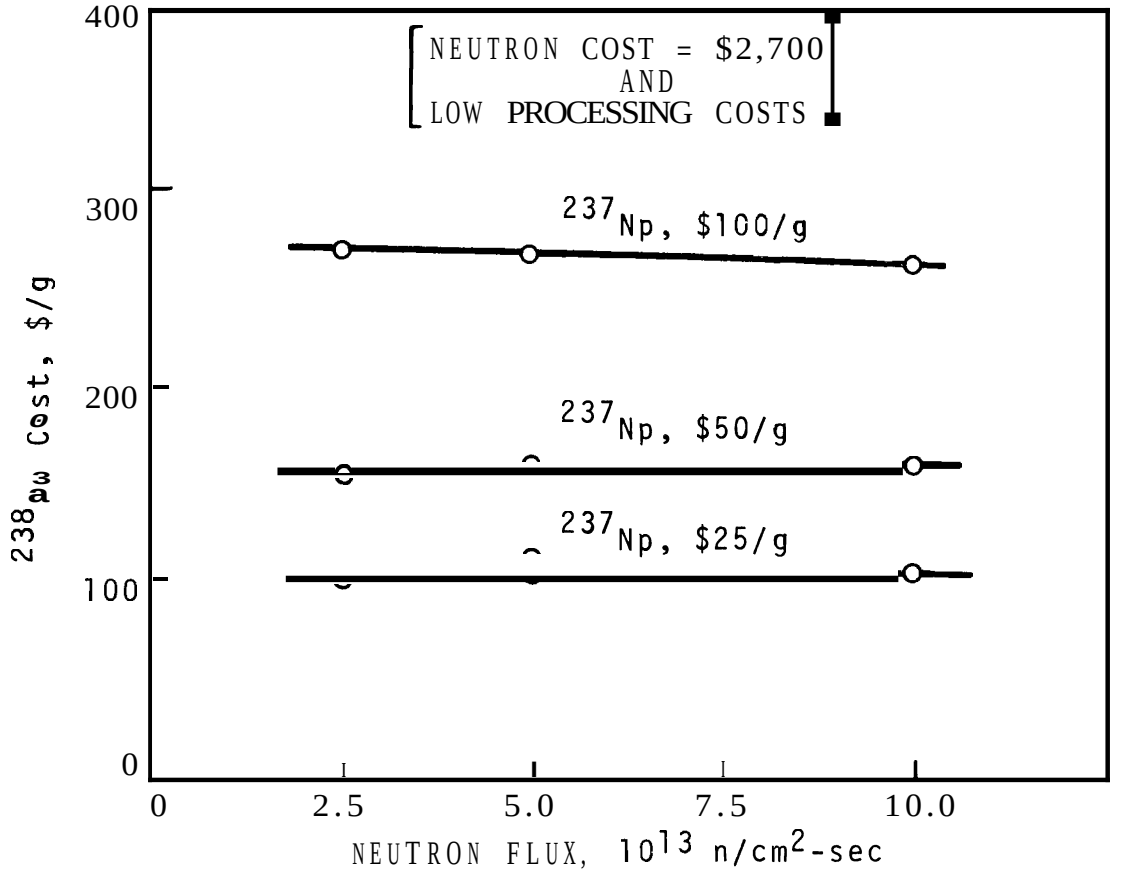


FIGURE 7.2. Effect of Neutron Flux and Neptunium Cost on the Cost of Producing ^{238}Pu with Neutrons Valued at $2,700/g and with Low Processing Costs

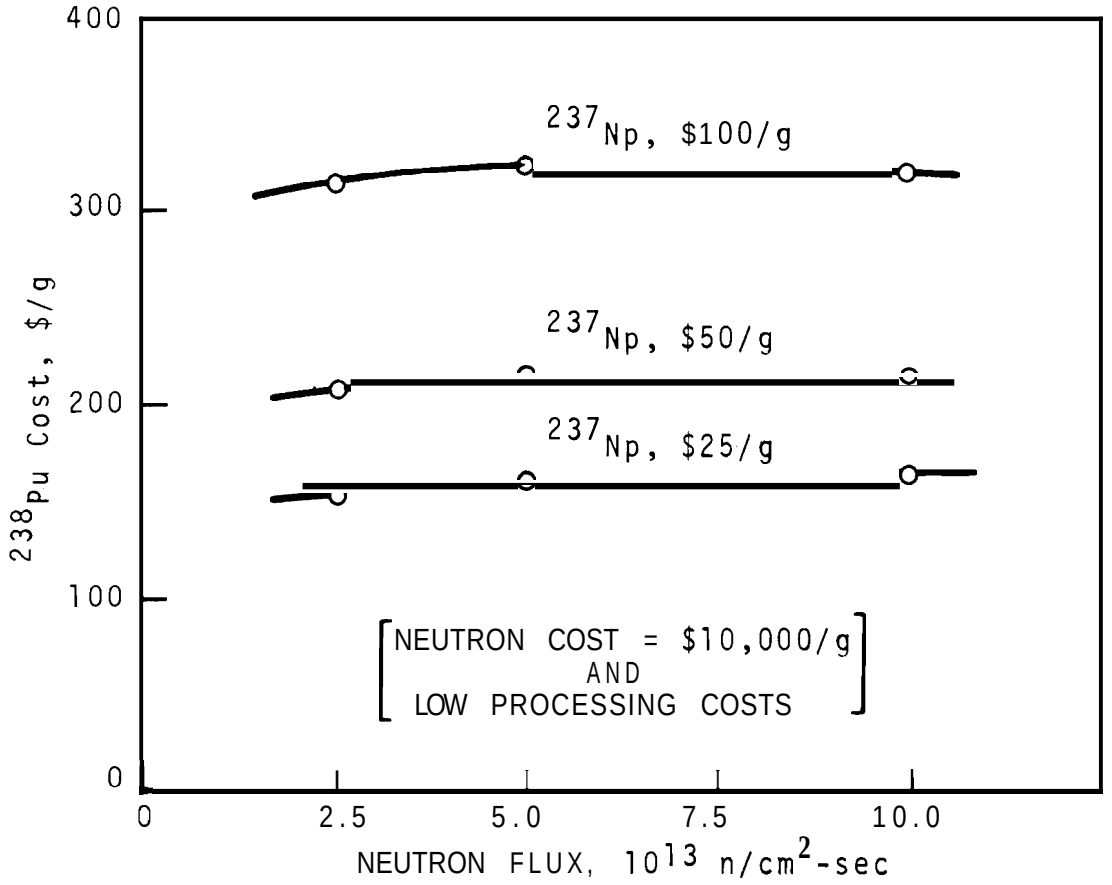


FIGURE 7.3. *Effect of Neutron Flux and Neptunium Cost on the Cost of producing ^{238}Pu with Neutrons Valued at $10,000/g and with Low Processing Costs*

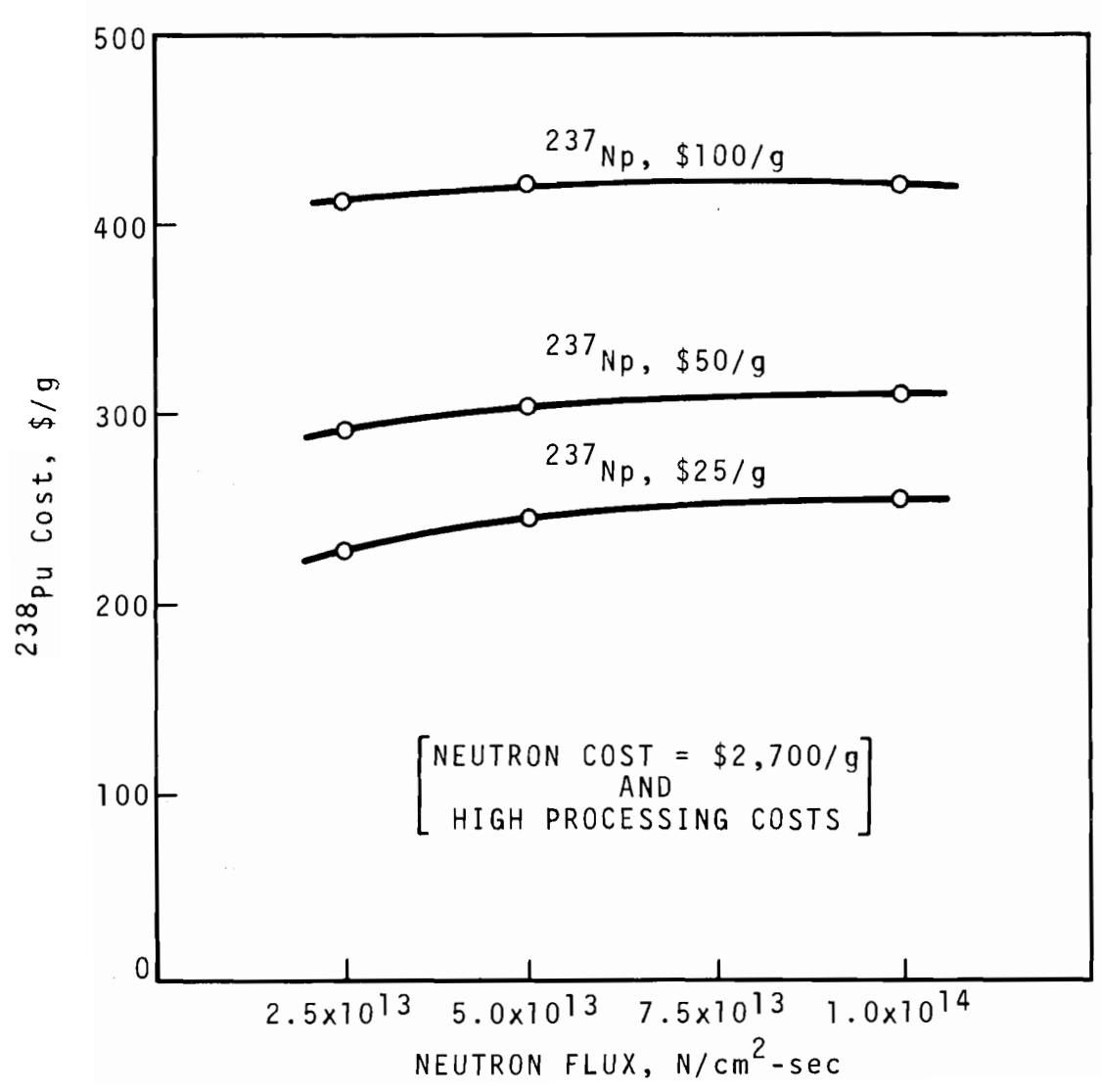


FIGURE 7.4. *Effect of Neutron Flux and Neptunium Cost on the Cost of Producing ^{238}Pu with Neutrons Valued at $2,700/g and with High Processing Costs*

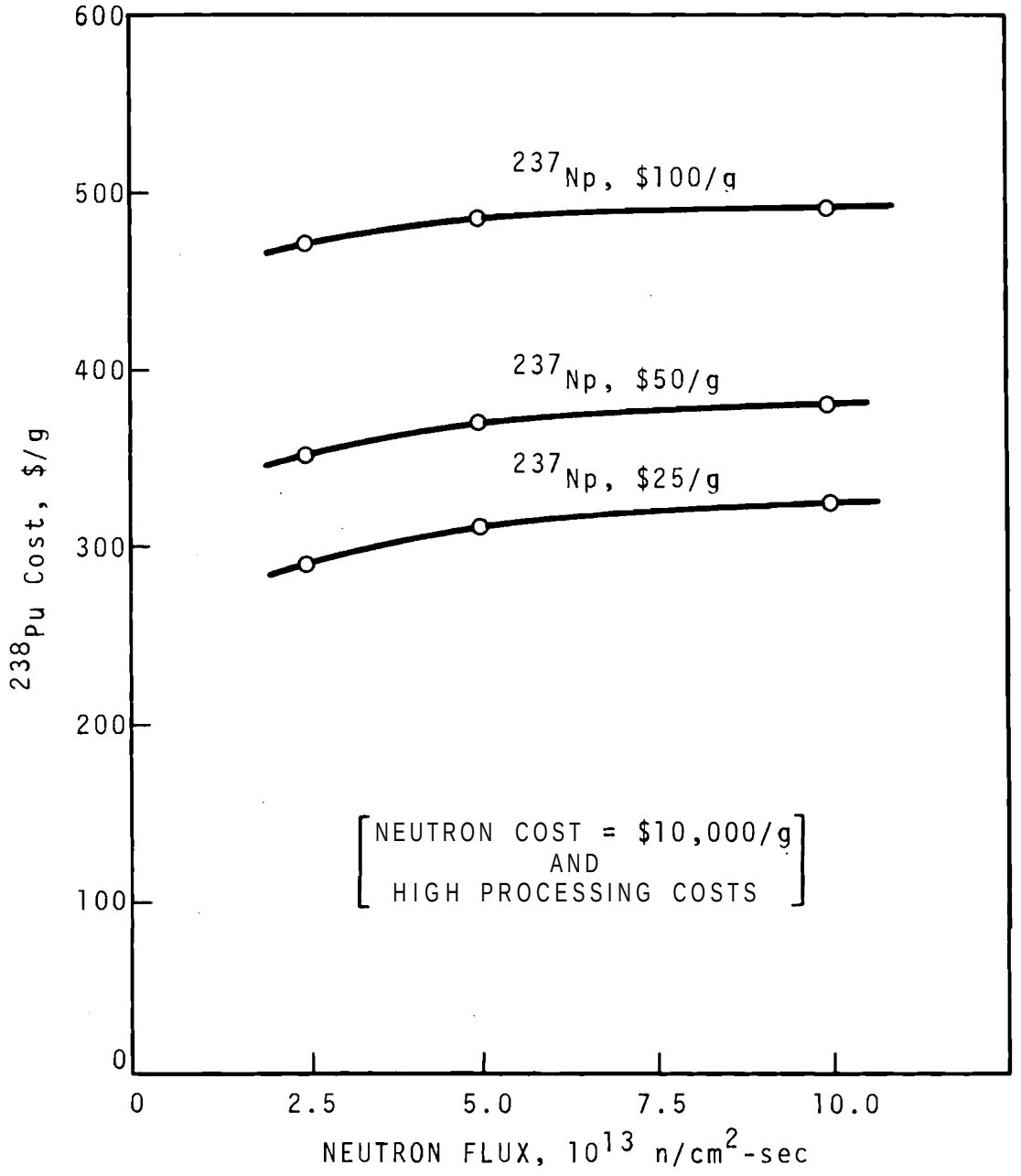


FIGURE 7.5. *Effect of Neutron Flux and Neptunium Cost on the Cost of Producing ^{238}Pu with Neutrons Valued at $10,000/g and with High Processing Costs*

The harder neutron spectrum (higher Westcott r value) in a power reactor results in an increased conversion rate through resonance captures and compensates in part for the high conversion rate at higher neutron fluxes. However, this is only part of the reason that high flux irradiation does not show a cost advantage. The reasons are complex and can be more easily understood by examining the yield and cost breakdowns in Tables 7.2 and 7.3:

- The optimum one-cycle yield at high flux tends toward a lower value to avoid excessive losses to ^{238}Np fission and this results in higher unit fabrication and reprocessing costs (included in "Other" costs in the tables).
- The ultimate yield at high flux is lower because of greater losses to ^{238}Np fission and higher processing losses (because of lower one-cycle yields) and this results in higher target material consumption and costs.
- At high flux the fixed reprocessing time is large in proportion to the optimum irradiation time and, as a result, the inventory cost advantage is not as large as one might expect.

These calculations indicate that, for a fixed set of input costs, there are only minor differences in the optimized ^{238}Pu production costs as a function of neutron flux. However, considering that the cost of neutrons in a power reactor is on the order of $2,700/g and that substantially higher neutron costs can be anticipated for high flux irradiations, power reactors offer the prospect of a cost advantage for ^{238}Pu production.

PRODUCTION OF TRANSURANIUM ELEMENTS IN LWRs

Neptunium availability from power reactor fuels has been evaluated in a study jointly sponsored by the Hanford Advanced Operations Planning Group and the AEC Division of Isotopes

TABLE 7.2. Plutonium-238 Cost and Yield Data for Low Processing Cost Cases with Neptunium Valued at $100/g

Flux, n/cm^2-sec	Optimum Irradiation Time, mo	One-Cycle Yield of ^{238}Pu, g/kg	Ultimate Yield of ^{238}Pu, g/kg	Production Costs, $/g of ^{238}Pu: ^{237}Np Target Material	Neutron Charge	Target Inventory Charge	Other	Total Costs
			$2,700/g of Neutrons					
2×10^{13}	14.1	173.8	660.7	151.4	19.0	73.9	29.1	273.4
5×10^{13}	7.6	172.8	625.9	159.8	20.0	57.1	34.2	271.1
1×10^{14}	4.1	154.2	609.0	164.2	20.4	44.7	37.7	267.0
			$10,000/g of Neutrons					
2×10^{13}	8.7	147.9	488.1	145.3	58.3	73.1	40.1	316.8
5×10^{13}	5.9	144.7	441.0	156.0	67.0	58.2	40.4	321.6
1×10^{14}	3.5	140.6	416.0	162.3	71.6	45.5	41.3	320.7

TABLE 7.3 Plutonium-238 Cost and Yield Data for High Processing Cost Cases with Neptunium Valued at $100/g

Flux, n/cm^2-sec	Optimum Irradiation Time, mo	One-Cycle Yield of ^{238}Pu, g/kg	Ultimate Yield of ^{238}Pu, g/kg	Production Costs, $/g of ^{238}Pu: ^{237}Np Target Material	Neutron Charge	Target Inventory Charge	Other	Total Costs
			$2,700/g of Neutrons					
2×10^{13}	20.4	258.1	634.1	157.7	21.4	80.4	154.3	413.8
5×10^{13}	13.7	238.3	583.9	171.3	24.2	63.3	162.7	421.5
1×10^{14}	7.4	218.0	560.1	178.6	25.5	44.6	173.1	421.8
			$10,000/g of Neutrons					
2×10^{13}	19.4	251.2	639.9	156.3	77.6	79.2	157.9	471.0
5×10^{13}	13.5	236.8	584.8	171.0	89.4	63.0	163.5	486.9
1×10^{14}	7.4	218.0	560.1	178.6	94.6	44.6	173.0	490.8

Development. A report on this study titled "A Survey of Fuel Reprocessor Plans for Recovering Neptunium and a Projection of Neptunium Quantities Available, through 1980," BNWL-1205, has been prepared for publication.

A questionnaire relating to plans and capabilities for neptunium recovery was sent to six companies either actively engaged in or with announced interest in fuel reprocessing ventures. Five of the six supplied answers to the questions and one stated that they were not able to provide the requested information at this time. Some of the responses noted that the answers should be considered confidential, so specific individual responses are not being identified.

The survey results show that substantial neptunium recovery facilities will be available in the near future even though a firm neptunium market has not yet developed. Neptunium recovery is a customer option and few, if any, actual commitments have been made for actual neptunium recovery. However, it is apparent that all reprocessors will provide and operate neptunium recovery facilities if a firm market does develop.

A high and low estimate of neptunium availability through 1980 was developed based on detailed fueling plans for currently committed reactors. The basic information was obtained in an AEC survey of electric utilities during the last quarter of 1968. The high estimate was based on current nuclear power plans extended to 150,000 MW_e of installed capacity in 1980 and a 90% recovery of neptunium. The low estimate was based on a more pessimistic schedule of nuclear additions extended to 120,000 MW_e of installed capacity in 1980 and a 70% recovery of neptunium.

The results of these two estimates are shown in Table 7.4. Neptunium availability is 9 to 12 kg/yr in 1970, increasing to 700 to 1100 kg/yr in 1980. Of the total projected neptunium

available over this period, 80 to 90% will be produced in reactors already committed for construction today. The high projection is a little lower than the earlier projection in BNWL-716[1] (15 kg/yr in 1970 increasing to 1200 kg/yr in 1980).

TABLE 7.4. Neptunium Availability Projections, kilograms

Calendar Year	High Estimate			Low Estimate		
	From Firm Sources	From Projected sources	Annual Total	From Firm Sources	From Projected sources	Annual Total
1970	12	--	12	9	--	9
1971	18	--	18	14	--	14
1972	57	--	57	38	--	38
1973	131	--	131	88	--	88
1974	232	--	232	155	--	155
1975	361	--	361	247	--	247
1976	491	--	491	353	--	353
1977	575	37	612	442	--	442
1978	674	150	824	487	24	511
1979	696	284	980	553	73	626
1980	691	433	1,124	532	147	679
Total	3,938	904	4,842	2,918	244	3,162

Reference

1. *D. E. Deonigi, R. W. McKee, and D. R. Haffner. Isotope Production and Availability from Power Reactors, BNWL-716. Battelle-Northwest, Richland, Washington, July 1968.*

RADIATION CHARACTERISTICS OF CIRCULATORY SUPPORT ISOTOPIC HEAT SOURCES

F. T. Cross and J. C. Sheppard

SHIELDING AND IN-PHANTOM DOSE PREDICTION

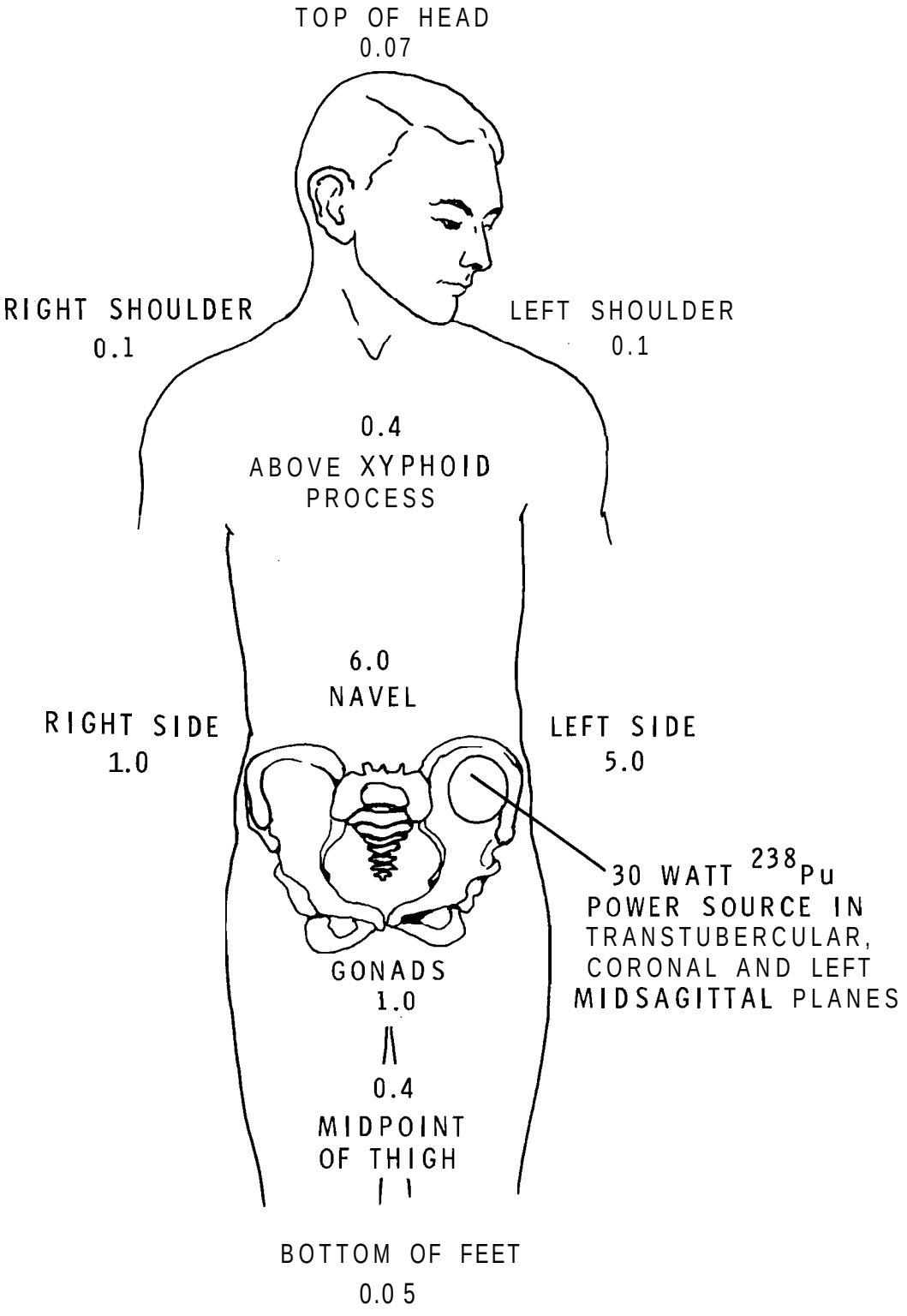
The Battelle Monte Carlo Code and Evaluated Nuclear Data File Compilation were used to determine the neutron fluence existing in a right circular tissue-equivalent phantom (35 cm diameter × 50 cm high) from a point ^{238}Pu source placed centrally within it. The Bach-Caswell energy transfer factors for tissue were then applied to determine fluence-to-dose conversion factors along the axis and radius of the phantom. The tentative conclusions are:

- No significant difference in the fluence-to-dose conversion factors for the axial and radial directions.
- Some disparity, but essentially good agreement with the fluence-to-dose conversion factors obtained by Irving, Alsmiller, and Moran at ORNL for 2 MeV monoenergetic and isotropically incident neutrons on a 30-cm slab of tissue.

It is yet to be determined whether the disparity is caused by poor statistics in the various calculations, differences in the geometries of the absorbing media and source positioning, or the use of an average neutron energy to represent the fission spectrum.

IN-PHANTOM DOSIMETRY MEASUREMENTS

Photon dose-rate profiles have been completed for planes perpendicular to the LASL-1 source axis starting at contact with the source heat exchanger end surface and extending 20 cm into tissue fluid. Measurements out the source radial direction are in progress. In addition, total dose-rates ($n + \gamma$) have been measured at selected sites on the surface of the Remab phantom. These are shown in Figure 8.1.



Neg 0694081

FIGURE 8.1. Dose-Rates (mrads/hr) on Surface of Remab Phantom

DISTRIBUTION

No. of Copies

OFFSITE

2 AEC Albuquerque Operations Office

1 AEC Chicago Patent Group
- G. H. Lee

202 AEC Division of Technical Information Extension

19 AEC Library, Washington
- J. N. Maddox (DID) (5)
- W. K. Eister (DID)
- G. A. Newby (SNS)
- R. T. Carpenter (SNS)
- F. C. Schwenk (SNS)
- G. P. Dix (SNS)
- J. A. Powers (SNS)
- J. S. Griffo (SNS)
- W. K. Kern (SNS)
- M. Klein (SNS)
- M. Shaw (DRDT)
- S. Seiken (DRDT)
- F. P. Baranowski (DP)
- G. B. Pleat (DP)
- W. Lenneman (DP)

2 AEC Oak Ridge Operations Office
- J. H. Kahn
- Dent C. Davis

1 AEC Sandia Area Office

1 AEC Savannah River Operations Office
- W. D. Sandberg

1 AEC Scientific Representative, London

1 Aerojet-General Nucleonics (SAN)
- W. G. Ruehl

1 Aerojet-General Corporation, San Ramon (NASA)

1 Aerospace Corporation, Los Angeles (AF)

No. of Copies	
1	Airesearch Manufacturing Company, Los Angeles
2	Air Force Aeronautical Systems Division
1	Air Force Headquarters
2	Air Force Weapons Laboratory
1	Army Reactors Field Group
1	Aro, Inc. (AF)
2	Avco Corporation (NASA) R. Y. Parkinson (1)
1	Bellcomm, Incorporated (NASA)
1	Bendix Corporation (NASA)
1	Brookhaven National Laboratory John Cusack
1	Central Intelligence Agency
2	Douglas Aircraft Corporation, MSSD (AF)
2	du Font Company, Aiken (AEC) D. H. Turno
1	General Dynamics, Fort Worth (AF)
1	General Electric Company (AEC) (NASA)
2	General Electric Company (MSD) (AEC)
1	General Electric Company, MSVD; Cincinnati M. Bromberg
1	General Electric Company, MSVD; Valley Forge P. E. Brown
1	General Electric Company, Vallecitos Laboratory J. I. Sweeney

No. of Copies	
1	Grumman Aircraft Engineering Corporation (NASA)
1	Hittman Associates, Inc. (AEC)
2	Hughes Aircraft Company, Aerospace Group, Culver City, California F. N. Magee K. W. Cowans
1	Institute for Defense Analyses (ARPA)
1	Lawrence Radiation Laboratory, Livermore (AEC)
1	Lockheed-Georgia Company (NASA)
1	Massachusetts Institute of Technology (AEC)
1	Massachusetts Institute of Technology (Lincoln) (AF)
2	Mound Laboratory (AEC) G. R. Grove R. L. Neubert
1	NASA Ames Research Center
4	NASA Goddard Space Flight Center W. C. Isley (1)
1	NASA Langley Research Center
8	NASA Lewis Research Center Lloyd Shure
2	NASA Manned Spacecraft Center Tony E. Redding (1)
1	NASA Marshall Space Flight Center
2	NASA, Washington
4	National Reactor Testing Station (Inc) (AEC)
1	Navy, Nuclear Power Division (Washington) Graham Haigie (NAVFAC)

No. of Copies	
1	Navy Air Development Center
1	Navy Air Systems Command
1	Navy Office of the Chief of Naval Operations
3	Navy Ordnance Systems Command
1	Naval Undersea Center F. Kawahara
1	Navy Ship Systems Command Headquarters
1	Navy Space Systems Activity
1	Nuclear Materials and Equipment Corporation (AEC) C. S. Caldwell
4	Oak Ridge National Laboratory (AEC) P. S. Baker A. F. Rupp E. Lamb S. J. Rimshaw
1	Public Health Service (HEW)
1	Radio Corporation of America (AEC)
1	Radio Corporation of America, Cranbury (AEC)
1	Rand Corporation (AF)
1	Republic Aviation Division (NASA)
1	Sanders Nuclear Corp., Nashua, N. H. Douglas Harvey
2	Sandia Corporation, Albuquerque (AEC) V. E. Blake G. J. Hildebrandt
	TRW Space Technology Labs, Redondo Beach, Calif. W. M. Bowes

No. of Copies

1 TRW Systems (AEC)

1 Westinghouse Electric Corporation, Lima (NASA)

1 Wright-Patterson AFB, Dayton, Ohio
Capt. D. C. De Pree

ONSITE-HANFORD

1 AEC Chicago Patent Group
R. K. Sharp (Richland)

2 AEC RDT Site Representative
P. G. Holsted

2 AEC Richland Operations Office
C. L. Robinson
B. A. Ryan

7 Atlantic Richfield Hanford Company
S. J. Beard
A. E. Smith
H. H. Hopkins
G. C. Oberg
P. W. Smith
R. E. Tomlinson
M. J. Szulinski

3 Battelle Memorial Institute

3 Donald W. Douglas Laboratories
R. L. Andelin
M. Lewis
Files

4 Douglas United Nuclear
J. W. Riches
R. G. Geier
D. W. Peacock
W. K. Woods

No. of Copies

39 Battelle-Northwest

E. M. Alpen
J. M. Atwood
E. A. Berreth/C. G. McCormack
A. G. Blasewitz
D. W. Brite
R. E. Burns
J. J. Cadwell
T. D. Chikalla
F. T. Cross
G. M. Dalen
R. L. Dillon
C. J. Denton
D. E. Deonigi
J. C. Fox
H. T. Fullam
J. E. Hansen
A. J. Haverfield
J. H. Jarrett
J. N. Judy
C. E. Leach
R. W. McKee/E. T. Merrill
R. L. Moore
R. E. Nightingale
A. M. Platt
F. P. Roberts
C. A. Rohrmann
W. F. Sheely
R. C. 'Thompson
H. H. Van Tuyl
J. B. Vetrano
E. E. Voiland
E. J. Wheelwright
Technical Information Files (5)
Technical Publications (2)