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A SURVEY OF FUEL REPROCESSOR PLANS
FOR RECOVERING NEPTUNIUM
AND A PROJECTION OF NEPTUNIUM
QUANTITIES AVAILABLE THROUGH 1980

October 1969

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A SURVEY OF FUEL REPROCESSOR PLANS FOR
RECOVERING NEPTUNIUM AND A PROJECTION OF
NEPTUNIUM QUANTITIES AVAILABLE THROUGH 1980

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October 1969

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ABSTRACT

This study indicates that substantial facilities for recovering neptunium from spent power reactor fuels are presently scheduled even though there is no neptunium market at the present time. This study estimates that during the period 1970 to 1980, the neptunium recovered could range from 9 to 12 kg/yr in 1970 and from 700 to 1100 kg/yr in 1980.

TABLE OF CONTENTS

	<u>Page No.</u>
INTRODUCTION	1
SUMMARY AND CONCLUSIONS	2
SURVEY OF NEPTUNIUM RECOVERY PLANS	3
NEPTUNIUM AVAILABILITY PROJECTION	7
Nuclear Power Growth Projections	7
Basis for Fuel Cycle Data	8
Effect of Fuel Exposure Uncertainty	11
Definition of Availability	14
Comparison of Reprocessing Load with Capacity	15
Neptunium Projections	15
REFERERCES	21

LIST OF FIGURES

<u>Figure No.</u>	<u>Title</u>	<u>Page No.</u>
1	Nuclear Power Projection, Current Plans Basis	10
2	Nuclear Power Projection, Pessimistic Basis	10
3	Variation of Neptunium Production in a PWR with Initial Fuel Enrichment and Final Exposure	12
4	Variation of Neptunium Production in a BWR with Initial Fuel Enrichment and Final Exposure	13
5	Comparison of Fuel Reprocessing Load with Scheduled Reprocessing Capacity Additions	16
6	High Neptunium Availability Projection	18
7	Low Neptunium Availability Projection	19

LIST OF TABLES

<u>Table No.</u>	<u>Title</u>	<u>Page No.</u>
	Nuclear Power Growth Projections, MWe	9
II	Neptunium Availability Projections, Kilograms	17

A SURVEY OF FUEL REPROCESSOR PLANS FOR
RECOVERING NEPTUNIUM AND A PROJECTION OF
NEPTUNIUM QUANTITIES AVAILABLE THROUGH 1980

INTRODUCTION

This report presents the results of a survey of the neptunium recovery plans of companies actively engaged in or interested in fuel reprocessing ventures. The report also includes results of a neptunium availability projection through 1980 which updates a previously published projection. (1) This study was co-sponsored by the Advanced Operational Planning Group at Hanford and the AEC Division of Isotopes Development,

Recovery of by-product isotopes during the reprocessing of spent nuclear-power-reactor fuels has attracted interest since power-reactor fuel reprocessing was first considered. At present, although there are promising prospects for other isotopes, neptunium-237 is the only isotope with sufficiently attractive marketing prospects to justify commitment of private capital for recovery facilities. However, even for this isotope, a definite market has not yet been established. Neptunium can be converted to plutonium-238 by neutron irradiation of neptunium targets in a nuclear reactor and the incentive for neptunium recovery derives from the attractive prospects that Pu-238 has as a heat source in remote power generating devices,

SUMMARY AND CONCLUSIONS

A survey of companies actively engaged in or with an announced interest in spent fuel reprocessing has shown that substantial neptunium recovery facilities are presently scheduled for the relatively near future. However, the extent to which actual neptunium recovery operations will be undertaken cannot be defined at this point in time because there is as yet no actual neptunium market. Firm plans and commitments for actual neptunium recovery are minor or non-existent. Our survey results indicate that neptunium recovery facilities, when operated, will be capable of recovering 70 to 90% of the neptunium present in the spent fuel.

A high and low estimate of neptunium availability through 1980 was developed using detailed information on fueling plans for individual reactors to the extent such information was available. The results show neptunium availability ranging from 9 to 12 kg/yr in 1970, increasing to from 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.

SURVEY OF NEPTUNIUM RECOVERY PLANS

To improve the basis for neptunium availability projections and to gain a better definition of prospects for actual neptunium recovery, we sent a questionnaire relating to plans and capabilities for neptunium recovery to six companies that are building or operating or have an announced interest in providing fuel reprocessing facilities. The response was excellent, with five completed questionnaires returned and one reply stating that they were not able at this time to provide the requested information.

In our letter requesting replies to the questionnaire we recognized that some of the questions might involve information that would not normally be publicized, and we stated that if the respondents would identify any responses considered confidential we would not publish these and would use the information only in averages or ranges of numbers or in generalized statements. Some of the respondents did request that we keep all or part of their answers confidential. Because of this, most of the responses are discussed here only in general terms.

The questions and responses are discussed in the following paragraphs.

Question 1: Do you at the present time plan to provide facilities for routine recovery of neptunium?

Replies established that substantial neptunium recovery facilities are presently scheduled and indicated that should a market develop there is little question but that all reprocessors will provide and operate neptunium recovery facilities. There is apparently a willingness, or perhaps a competitive necessity, to risk some investment in neptunium

facilities, but the responses indicated that it is difficult to justify neptunium facilities in the present climate of uncertain markets.

Specific plans for neptunium recovery facilities that can be identified include installations in General Electric Company's 1 MTU/day Midwest Fuel Recovery Plant, scheduled for commercial operation in mid-1971, and Allied Chemical Corporation's 5 MTU/day Barnwell Nuclear Fuels Plant, scheduled for operation in mid-1973. Scope engineering and detailed cost estimates have been completed for addition of neptunium facilities to the Nuclear Fuel Services Plant (scheduled to increase capacity from 1 MTU/day to 3 MTU/day by mid-1973), and NFS will add these facilities if and when neptunium recovery is requested by their utility customers.

One respondent indicated a possible interest in neptunium recovery for plutonium-238 production via toll irradiation of the neptunium, should a firm plutonium-238 market develop. Others felt that neptunium recovery is dependent on AEC policy. For example one respondent stated, "Frankly, unless the AEC establishes a policy to purchase neptunium there will be no market, and except for the very early period, none will be recovered."

Question 2: If you are planning for neptunium recovery,

- (a) at what date do you anticipate these facilities will be available?
- (b) will all neptunium be recovered or will this be entirely a customer option?
- (c) will the neptunium present in fuel processed prior to completion of recovery facilities be nonrecoverable?

- (d) can you supply us with any information on your own projections of firm neptunium recovery quantities from your own plant?

Replies indicated that where neptunium recovery facilities are scheduled, they will be available with new plant startups, but that the actual neptunium recovery is a customer's option. Since recovery facilities will be available with plant startup, the question of neptunium losses prior to availability of recovery facilities was not applicable. No information was obtained regarding projections of neptunium recovery from individual plants except "nil" or an indication that it's too early to make meaningful projections.

Question 3: If you are not now planning neptunium recovery,

- (a) will the unrecovered neptunium be irretrievably lost?
- (b) will the unrecovered neptunium be recoverable but at extra expense compared to neptunium in current fuel processing if recovery facilities are added at some future time?
- (c) what time interval would you anticipate as required for neptunium recovery facilities to be placed in operation following a firm decision to recover neptunium?

Replies indicated that neptunium would not be irretrievably lost, but that neptunium recovery at a later date would probably involve extra cost. It was indicated that a six-month to twelve-month period would be required to install recovery facilities in an existing plant. Presumably in any such case provisions would have been made during initial construction for adding such facilities later, as is the case with the existing Nuclear Fuel Services plant.

Although neptunium recovery after initial discard was indicated as possible, there may be only a limited period during which this might be accomplished. Presuming that the neptunium ends up in high level waste that is ultimately converted to solid form for perpetual storage, the neptunium at that time probably could not be recovered at a practical cost.

Question 4: If neptunium recovery is a customer's option, can you supply us with any information on the proportion of your customers who are requesting neptunium recovery?

Answers indicated that few, if any, firm commitments have been made for neptunium recovery, and that it is too early to make meaningful estimates.

Question 5: What would you consider as a normal time lapse for the period from reactor discharge to neptunium recovery?

Answers vary from a minimum of 5 months to a maximum of 7 months and a maximum of 12 months, with an average value of 7 months.

Question 6: In your consideration of neptunium recovery, would you (or do you) consider your neptunium product adequately purified or decontaminated to go directly to a target fabrication process, or would further decontamination processing be required?

Where definitive recovery plans had been made, all replies indicated that the product would be suitable for direct use without further processing.

Question 7: What fraction of the neptunium present in spent fuel do you consider to be recoverable?

Where definitive recovery plans had been made, replies were within the range of 70 to 90%.

NEPTUNIUM AVAILABILITY PROJECTION

A high and low estimate of neptunium availability through 1980 was developed using detailed information on fueling plans for currently committed individual reactors to the extent such information was available. These estimates also incorporate some refinements in the basic data and assumptions in comparison to the basic data and assumptions used to produce the neptunium projections in BNWL-716.⁽¹⁾

There are several sources of uncertainty in determining future neptunium availability. These include

- (a) startup dates for committed nuclear power reactors
- (b) the number of additional power reactors that will be ordered during the period of interest
- (c) the capacity factors after the reactors are placed in operation
- (d) the fuel cycle; that is, enrichment, exposures and discharge dates for startup and equilibrium fuel cycles
- (e) neptunium content in the spent fuel at specified exposures
- (f) the time interval between fuel discharge and recovery, and the fraction of neptunium that can or will be recovered.

We have used the best available data to minimize these uncertainties, but since all uncertainty cannot be eliminated, we felt it could best be recognized by developing the neptunium availability projection in terms of a high and low estimate.

Nuclear Power Growth Projections

High and low nuclear power growth projections were first prepared. The high projection represents an achievement of current objectives and

might be viewed as optimistic in the light of continuing reports of nuclear project delays. The low projection represents slipped goals and a generally pessimistic viewpoint. The AEC's Division of Industrial Participation April 15, 1969 listing of central-station nuclear plants constituted the basis of the high or current-plans nuclear growth projection. In addition, it was assumed that there would be 150,000 MWe of installed nuclear power capacity by the end of 1980. The low or pessimistic nuclear growth projection incorporates recently announced^(2,3) probable startup delays and an across-the-board delay of one year for one-third of all currently scheduled plants, and assumes that the installed nuclear power at the end of 1980 will reach only 120,000 MWe.

The nuclear power projections are shown in Table I and Figures 1 and 2. Neither projection includes the Hanford NPR, Shippingport, Fermi, Peach Bottom No. 1, Elk River or Lacrosse reactors. The area under the curves is a rough measure (depends on capacity factor) of the energy production and shows that in either case, the major portion of the energy that will be produced by nuclear power between now and 1980 will be produced in plants already committed today.

Basis for Fuel Cycle Data

Results of an AEC survey of electric utility fueling plans for scheduled reactors were used as the basis for determining neptunium production from as many reactors as possible. The AEC survey data were accumulated during the last quarter of 1968 and provided estimates of U-235 withdrawals and transfers to the AEC. Using these data in combination with a compilation of parametric burnup data from a study⁽⁴⁾ for the

TABLE I
NUCLEAR POWER GROWTH PROJECTIONS, MWe

Calendar Year	Current-Plans Basis			Pessimistic Basis		
	Committed Additions	Projected Additions	Cumulative Total	Committed Additions	Projected Additions	Cumulative Total
1968 and Prior*	1,780	--	1,780	1,780	--	1,780
1969	1,430	--	3,210	1,430	--	3,210
1970	7,100	--	10,310	5,160	--	8,370
1971	8,000	--	18,310	8,030	--	16,400
1972	12,820	--	31,130	10,500	--	26,900
1973	13,240	--	44,370	13,060	--	39,960
1974	10,980	--	55,350	11,780	--	51,740
1975	6,908	6,670	69,000	8,420	--	60,160
1976	--	15,000	84,000	2,170	5,670	68,000
1977	2,120	12,880	99,000	2,120	6,880	77,000
1978	--	16,000	115,000	--	12,000	89,000
1979	--	17,000	132,000	--	15,000	104,000
1980	--	18,000	150,000	--	16,000	120,000

*Excluding Hanford NPR.

FIGURE 1
Nuclear Power Projection, Current Plans Basis

FIGURE 2
Nuclear Power Projection, Pessimistic Basis

IAEA completed last year, it was possible to estimate exposure and neptunium content of the spent fuel. Sufficient data were available in the AEC survey results to provide neptunium estimates for 33,000 MWe out of a total of 64,500 MWe of total scheduled capacity additions.

For the reactors not covered in the AEC survey data and for projected reactors not yet committed, the reactor fueling histories for the 1970-design BWR and PWR in BNWL-716⁽¹⁾ were used, except that the neptunium content was modified. The burnup calculations for the histories in BNWL-716 and for the IAEA study were both developed with the ALTHAEA⁽⁵⁾ program, but the cross section library for the IAEA calculations had been modified, producing about 10 to 15% less neptunium for a given set of conditions. The modifications were the result of further program calibrations against analyses of Yankee reactor fuel.

Effect of Fuel Exposure Uncertainty

One of the uncertainties in developing a neptunium projection involves fuel exposure. Startup or first-core fuel exposures will probably average around 20,000 MWD/MT, and equilibrium exposures will probably exceed 30,000 MWD/MT, but conceivably could vary considerably over the ten-year period from 1970 to 1980. The initial U-235 enrichment of the fuel also affects neptunium production since the main source of neptunium is successive capture of two neutrons in U-235.

To better identify the uncertainties involving exposure and enrichment, Figures 3 and 4 show the variation of neptunium production rate with exposure and initial enrichment for a typical PWR and a typical BWR (at 100% capacity factor and assuming 32% thermal efficiency).

FIGURE 3
Variation of Neptunium Production in a PWR with Initial Fuel Enrichment and Final Exposure

FIGURE 4
Variation of Neptunium Production in a BWR with Initial Fuel Enrichment and Final Exposure

Figures 3 and 4 are based on data from the IAEA study.⁽⁴⁾ The probable area of equilibrium fuel-cycle operation is indicated by a crosshatched area on each figure and shows that the maximum uncertainty from these factors is about 1 1/2 kg/yr/1000 MWe out of about 15 kg/yr/1000 MWe, or approximately 10% ($\pm 5\%$ around a median value). Thus, possible variations in fuel exposure and enrichment do not introduce a serious uncertainty into the projections.

Definition of Availability

For determination of neptunium availability from reactors where data was provided by the AEC survey, it was assumed that neptunium would be available (recovered) at the same time that spent-fuel U-235 was transferred to the AEC. For the other reactors a six-month period between reactor discharge and availability was assumed. The assumption was based on the results of our survey of reprocessors, and represents a reduction from the one-year assumption in BNWL-716.⁽¹⁾

As indicated previously, we concluded from the results of our survey of reprocessing plans that if a firm market develops, all reprocessors will provide and operate neptunium recovery facilities. The Nuclear Fuel Services plant is the only reprocessing plant operating today, and this plant does not have separate neptunium recovery facilities. However, the plant could be operated to recycle the high level waste on an intermittent basis for neptunium recovery. Although such operation would exclude reprocessing during neptunium recovery, it would be possible when the full-plant capacity is not required for fuel reprocessing (next 2 to 3 years). This method of neptunium recovery would be expensive and may not

be economically attractive, but at least in the sense that recovery is technically possible, neptunium recovery could be initiated now. For the neptunium availability projections in this study, availability is used in the sense that the neptunium is technically available but recovery may or may not be economically attractive.

Comparison of Reprocessing Load With Capacity

A comparison of fuel reprocessing load with existing and scheduled reprocessing capacity additions is shown in Figure 5. The schedule of planned new reprocessing capacity additions indicates that excess reprocessing capacity will be available over the entire period of interest (1970-80). Thus, there should be no question of the feasibility of realizing the recovery of the neptunium quantities indicated in our availability projections, provided of course that sufficient economic incentive develops and that the required facilities are added in all cases. There could even be a deferral of several years in one of the scheduled plants without changing this conclusion.

Neptunium Projections

Our survey of reprocessors indicates a possible range in neptunium recoveries from 70 to 90%. The high neptunium projection incorporates the high (current plans) nuclear power projection with a 90% recovery of neptunium. The low neptunium projection incorporates the low (pessimistic) nuclear projection with a 70% neptunium recovery. The results are shown in Table II and Figures 6 and 7. That the 1980 firm neptunium availability is slightly reduced from the 1979 amount is not significant, and is due to the non-uniform nature of some of the first-core fuel discharges.

FIGURE 5
Comparison of Fuel Reprocessing Load with Scheduled
Reprocessing Capacity Additions

TABLE II
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	<u>691</u>	<u>433</u>	<u>1124</u>	<u>532</u>	<u>147</u>	<u>679</u>
TOTALS	3938	904	4842	2918	244	3162

FIGURE 6
High Neptunium Availability Projection

FIGURE 7
Low Neptunium Availability Projection

The total area enclosed in the bars in Figures 6 and 7 represents the cumulative total of potential neptunium recovery during the period. The crosshatched area represents the neptunium from firm sources, that is, reactors that are committed today. These results show rather clearly that the major portion of the neptunium production up through 1980 will be from reactors already committed for construction today. This is particularly true in the low case where over 90% of the total neptunium is from reactors already committed; however, even in the high case, committed reactors account for 80% of the total neptunium.

The high projection shows 12 kg/yr in 1970 increasing to 1100 kg/yr in 1980, with 700 kg/yr in 1980 produced from reactors already committed. This projection is slightly lower than the 15 to 1200 kg/yr projected in BNWL-716 for the same period.

The low projection shows 9 kg/yr in 1970 increasing to 700 kg/yr in 1980, with 500 kg/yr in 1980 produced from reactors already committed.

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