AIM

Association for Information and Image Management

1100 Wayne Avenue, Suite 1100
Silver Spring, Maryland 20910
301/587-8202

Centimeter

Inches

MANUFACTURED TO AIM STANDARDS
BY APPLIED IMAGE, INC.

1 of 1

(CLASSIFICATION

HANFORD ATOMIC PRODUCTS OPERATION - RICHLAND, WASHINGTON

DEL

A

October 21, 1963

(CLASSIFICATION)

DECLASSIFIED

HW-79306-DEL

This document consists of
22 pages. No. [redacted] of
[redacted] copies. Series [redacted]

PRODUCTION OF SPECIAL NUCLEAR MATERIALS

IN N-REACTOR

DECLASSIFIED
WITH DELETIONS

BY

D. L. Condotta

E. G. Pierick

By Authority of CE-NMP-0001
5M/tem 5/9/94
By DG/Brakes 5/10/94
Verified By PM/Eck 5-10-94

This document contains information that is classified in one Atomic
Energy Act of 1954, or the Atomic Energy Act of 1954, or its
contents in any manner to an unauthorized person is prohibited.

HANFORD ATOMIC PRODUCTS OPERATION
RICHLAND, WASHINGTON

NOTICE

MASTER

This report was prepared for use within General Electric Company in the course
of the performance of contract with the Commission under Contract AT(45-17)-1501. Any
views or opinions expressed in the report are those of the author. This report
is subject to revision upon collection of additional data.

LEGAL NOTICE

This report was prepared on account of Government sponsored work. Neither the United States,
nor the Commission, nor any person acting on behalf of the Commission

A. Makes any warranty, representation, expressed or implied, with respect to the accuracy, com-
pleteness, or usefulness of the information contained in this report, or that the use of any information,
apparatus, method, or process disclosed in this report may not infringe privately owned rights; or

B. Assumes any liability with respect to the use of, or for damages resulting from the use of
any information, apparatus, method, or process disclosed in this report.

As used in the above, "person acting on behalf of the Commission" includes any employee or
contractor of the Commission, or employee of such contractor, to the extent that such employee or con-
tractor of the Commission, or employee of such contractor prepares, disseminates, or provides access to,
any information pursuant to his employment or contract with the Commission, or his employment with
such contractor.

DECLASSIFIED

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISTRIBUTION

1. - 6. AEC-RLOO,
Attn: J. E. Travis
7. T. R. Clark - E. D. Sayre
8. D. L. Condotta
9. D. H. Curtis
10. R. L. Dickeman
11. W. J. Dowis
12. O. H. Greagor - T. W. Ambrose
13. T. W. Evans
14. A. B. Greninger
15. K. G. Grimm - J. E. McDonald
16. W. M. Harty
17. W. E. Johnson
18. H. R. Kosmata
19. M. C. Leverett
20. L. M. Loeb
21. L. W. Lang
22. W. M. Mathis
23. J. S. McMahon
24. J. Milne
25. P. F. Nichols
26. E. G. Pierick
27. P. H. Reinker - R. E. Tomlinson
28. J. W. Riches
29. R. J. Shields
30. S. H. Small
31. D. R. Stenquist
32. R. E. Trumble
33. Record Center
34. 300 File
- 35.-39. Extra

DECLASSIFIED

PRODUCTION OF SPECIAL NUCLEAR MATERIALS
IN N-REACTOR

<u>TABLE OF CONTENTS</u>	<u>Page</u>
I. INTRODUCTION	4
II. SUMMARY AND CONCLUSIONS	4
III. DISCUSSION	6
A. GENERAL	6
B. METALLURGY PARAMETERS	8
1. DRIVER ELEMENT	8
2. TARGET ELEMENT	10
3. MECHANICAL DESIGN	11
C. PHYSICS CALCULATIONS	11
IV. ECONOMIC PARAMETERS	13
V. RESEARCH AND DEVELOPMENT	17
A. REACTOR PHYSICS	17
B. MATERIALS	18
C. THERMAL-HYDRAULICS	19
D. ESTIMATE OF RESEARCH AND DEVELOPMENT COSTS	19
VI. CAPITAL EXPENDITURES	20
VII. SCHEDULE	20
VIII. ACKNOWLEDGMENTS	22

DECLASSIFIED

**DECLASSIFIED
WITH DELETIONS**

HW-79306 - DEL
Page 4

PRODUCTION OF SPECIAL NUCLEAR MATERIALS

IN N-REACTOR

I. INTRODUCTION

In the summer of 1962, a brief scoping study of the N-Reactor's capability as a producer of tritium concurrently with plutonium and steam was completed and documented.⁽¹⁾ This study indicated that there might be considerable incentive in pursuing the development of a multi-product mode of operation of the N-Reactor. Early in 1963 reports⁽²⁾⁽³⁾ presented the preliminary production and cost data, and brief discussions of the potential technical problems which may arise in a multi-product mode of operation. On September 9, 1963, a report⁽⁴⁾ presented a program for the conversion of the N-Reactor to the concurrent production of weapon grade (6%) plutonium and substantial quantities of tritium. The production and cost data showed that the amount of tritium can be varied over a wide range and that weapon grade plutonium can be economically generated.

The purpose of this report is to evaluate the feasibility and incentive for operation of the N-Reactor with fully enriched fuel producing only two major products, tritium and steam. Neptunium 237 is an important by-product.

II. SUMMARY AND CONCLUSIONS

Operation of the N-Reactor to produce tritium and steam as major products is based on the use of a fuel element consisting of a fully enriched uranium driver piece and lithium-aluminum targets pieces. A specific fuel design was developed during this study to provide a basis for production and cost estimates. This fuel design is consistent with our present knowledge of the physics and engineering criteria involved, however considerable research and development and analytical studies would be necessary to mature an optimum fuel design. The unit costs and production numbers presented in this report are based on the reference design. It is believed that these numbers are on the conservative side, and that an appropriate research and development program, and utilization of the experience of a multi-product program,⁽⁴⁾ will show methods of reducing the estimated production costs.

This study indicates that the N-Reactor would be able to produce approximately 14 Kg of tritium per year, when operated with a fully enriched fuel design and at a thermal power level of 4000 MW. Production cost numbers have been developed based on the use of a Zircaloy-Uranium matrix for the driver element. These studies indicate a unit production cost of _____ when appropriate credit is taken for steam and neptunium. These costs are based on

(1) HW-74684, "Tritium Production in the NPR," T. W. Evans to R. J. Shields, August 21, 1962

(2) HW-76242, "Preliminary Study of NPR Production Capabilities," K. W. Norwood, et al, February 11, 1963

(3) HW-77198, "Production Studies - N-Reactor," N-Reactor Department Staff, April 4, 1963

(4) HW-78864, "A Program for Multi-Product Operation of N-Reactor," Staff - Research and Engineering Section, N-Reactor Department, September 9, 1963

**DECLASSIFIED
WITH DELETIONS**

██████ DECLASSIFIED

HW-79306 -DEL
Page 5

equilibrium operation several years in the future and assume that sufficient time is available to mature the necessary technology for use of a fully enriched fuel in the N-Reactor.*

It should be noted that the unit costs for tritium-only production are higher (on an equivalent gram of Pu basis) than those previously reported for multi-product operation of the N-Reactor.⁽⁴⁾ This occurs for several reasons -- higher burnout costs, lower neutron utilization efficiency, and higher fuel fabrication and handling costs when using fully enriched material. It thus is concluded that the tritium-only mode of operation is not the optimum method of operating N-Reactor as long as some plutonium production is required for weapons material. Previous studies⁽⁴⁾⁽⁵⁾ have shown the economic incentives for operating N-Reactor as a co-producer to produce about 5 Kg of tritium per year. Further optimization studies may show that the most economic method of operation would produce somewhat greater quantities of tritium.

The use of a fully enriched loading in the N-Reactor represents the most complex mode of operation so far seriously considered. Thus it is reasonable to expect a number of technical problems that must be solved to make such an operation feasible. This study has identified two specific problem areas; namely, a significant increase in the amount of heat generated in the moderator, and the necessity for showing that the driver-target fuel concept will meet nuclear control requirements during all credible incidents. The exact seriousness of these problems cannot be specifically defined at this time and will depend to some extent on the control and operating characteristics of the reactor. Solutions to these two problems can undoubtedly be obtained, although it is possible the solutions might require significant changes in the fuel concept and operating conditions used as a basis for this study.

All other problem areas appear to be of a routine nature and should be resolved by an adequate supporting research and development program. The costs of an adequate research and development program are estimated to be about \$ 4 million dollars over the basic technology needed for the plutonium production program. However, if a multi-product (tritium and plutonium) program is developed for the N-Reactor over the next several years,⁽⁴⁾ then the additional R&D costs necessary to mature a fully-enriched technology should be about \$1.6 million.

The capital costs associated with a fully enriched program would also depend on the base that is assumed. The additional costs over a Multi-Product program⁽⁵⁾ are estimated to be about \$1,000,000 to \$2,000,000.

*Recent communications from the AEC indicate that costs developed for the year 1972 would be of most interest in evaluating the tritium-only mode of operation. The costs presented in this study have assumed a base equilibrium year some 5 years or so in the future. It is believed the costs are conservative when applied to the year 1972.

(4) HW-78864

(5) HW-78671, "Special Product Study - N-Reactor," R. L. Dickeman,
August 16, 1963

██████████

**DECLASSIFIED
WITH DELETIONS**

HW-79306-DEL
Page 6

Based on this preliminary study, it is concluded that the N-Reactor could be used to maintain a large tritium stockpile by operation with a fully enriched load to produce 14 Kg of tritium per year at an economically competitive price of . Conversion of the N-Reactor to a fully enriched loading will require the solution of certain technical problems; and an orderly and well defined development program would require timing such a program for about 1968 or later. If it is consistent with the AEC's continuing product requirements, a logical program would be to first convert the N-Reactor to Multi-Product operation. Development of a multi-product technology, and the resulting operational experience would be directly applicable to a fully-enriched program. Multi-Product operation would also confirm many of the calculation procedures and cost estimates used in this study. Thus a subsequent conversion to a fully enriched mode of operation would not involve such a large extrapolation from available data as is now required.

There is significant incentive, however, to warrant a continuing program to develop the necessary technology for a fully enriched program, or more broadly for a multi-product capability covering the spectrum of 3-14 Kg of tritium production to meet whatever product requirements that may develop. Continued work on such a program is recommended.

III. DISCUSSION

A. General

Engineering studies⁽²⁾⁽³⁾⁽⁴⁾⁽⁵⁾ have shown that the N-Reactor can be advantageously adopted to the concurrent production of tritium and plutonium. This can be done by modifying the fuel charge in the reactor so that a portion of the uranium-238 target material is replaced with lithium-6 isotope contained in a lithium-aluminum alloy target material. By replacing a majority of the uranium-238 in the reactor with lithium-6 isotope, the uranium contained in the fuel driver element becomes alloy and tritium production is maximized.

The Phase I N-Reactor fuel element consists of a coaxial dual tube design. Both tubes are of co-extruded uranium (0.947 w/o U-235) in Zircaloy-2 cladding. The conceptual fuel design for this study departs from the tube-in-tube (Pu only) or from the single-tube and target (multi-product) to a more complex tube-in-tube and target rod design (tritium-only). The outer tube (gray target) is an extruded aluminum-2 w/o lithium of about 19 w/o lithium-6 covered with thin aluminum clad followed with a thin Zircaloy-2 clad. The inner tube (driver element) is a coextruded tube of zirconium-30 w/o uranium of 93% enrichment in Zircaloy-2 cladding. The inner rod (black target) located centrally in the driver tube is an extruded aluminum-3.5 w/o lithium of about 95 w/o lithium-6 covered with thin aluminum clad followed with a thick Zircaloy-2 clad. (See Figure 1)

- (2) HW-76242
- (3) HW-77198
- (4) HW-78864
- (5) HW-78671

**DECLASSIFIED
WITH DELETIONS**

FIGURE 1
TYPICAL FUEL COLUMN
CROSS-SECTION SHOWING AN ALL TRITIUM
PRODUCTION CONFIGURATION

DECLASSIFIED

DECLASSIFIED

HW-79306-DEK
Page 8

The conceptual fuel assembly was designed to operate in the N-Reactor at a driver specific power of about 170 KW/ft compared to 123 KW/ft and 47.4 KW/ft for the outer and inner driver tubes of the fuel element for first loading of the N-Reactor. The fuel assembly will be expected to sustain an average irradiation lifetime of 100,000 MWD/T uranium or about a residence time in the reactor of about 380 full power days at a power level of 4000 MW.

B. Metallurgy Parameters

1. Driver Element

The fuel driver shown in Figure 1 is a thin-walled, large diameter coextruded tube of zirconium-30 w/o uranium of 93% enrichment in Zircaloy-2 cladding. The proposed driver element will operate with a maximum fuel core temperature near 590°C. It is estimated that a volume increase of about 7 per cent at an average fuel exposure of 2 per cent burnup will result in a maximum uniform circumferential strain in the outer cladding of 1 per cent. This estimate assumes that the inner diameter remains constant and the outer diameter increases as the fuel swells. The probable response of the fuel element to increasing fuel volume will be increases in the outer diameter and decreases in the inner diameter until buckling of the inner cladding occurs. After buckling starts, all of the subsequent deformation will be inward. Since only bending stresses are involved, the inner cladding will probably not fail mechanically but, rather, thermal hydraulic considerations will determine the fuel life limits. At present, the available data indicate that the fuel will probably be adequate to 2 per cent burnup at temperatures below 595°C.* A limit of 2 per cent burnup corresponds to an exposure of 100,000 MWD/T uranium for this particular fuel composition.

The driver tube will operate with a peak heat flux of about 580,000 Btu/hr-ft². Burnout flux in the range of operating conditions is above 1,000,000 Btu/hr-ft². Thus, burnout is not expected to be a serious limit during steady-state operation.

The composition of the fuel driver lies in the two phase region of the equilibrium diagram, the two phases being α (Zr containing less than 0.3% w/o uranium in solid solution) and δ (the only intermediate phase in the system, occurring at about the composition corresponding to U Zr₂).

At temperatures above 595°C the delta phase transforms to gamma. At fuel temperatures above this transition point, the swelling rate of the fuel has been found to be much greater than expected. This increase is presumed to be caused by nucleation of fission gas bubbles during the transition. Therefore, fuel temperatures above 595°C should be avoided.

* Tests of this fuel composition, carried out at Knolls Atomic Power Laboratories (KAPL) have shown satisfactory operation at exposures up to 2 - 3% burnup of total atoms and at fuel temperatures above 595°C.

DECLASSIFIED

HW-79306-DEL
Page 9

Fabrication of the fuel elements from either alpha phase or delta phase is straightforward and presents no difficulties. Although the mixture of the two phases is physically harder than either of the phases individually, fabrication, while not significantly more difficult, is rather sensitive to the heat treatment history of the alloy. Cladding of the fuel with Zr-2 by coextrusion is expected to be straightforward with bonding and cladding uniformity problems being greatly reduced as compared with the current fuel. Recessing the ends of the fuel components prior to closure would probably be done mechanically because of the relative chemical inertness of the fuel. Zr-2 end caps would be used and closure would be effected by TIG welding.

The corrosion resistance of these fuel alloys is greatly superior to that of uranium. While this alloy is not what would be called a "stainless" fuel it is nearly so. In one series of tests by WAPD, exposure to 340°C water for 100 days led to less than 10 mils uniform corrosion.

This fuel has found wide use where good performance to high exposure, in high temperature water is required. It has been used extensively in nuclear powered submarines. The "seed" elements of the PWR are Zr clad roll-bonded flat plates of Zr-U fuel. The "Driver" elements of the HWCTR are Zr-2 clad coextruded thin-walled large diameter tubes of Zr-U fuel. The performance of the HWCTR fuel with irradiation exposures up to nearly 2 per cent burnup has been good.

In an early phase of this study, use of aluminum-uranium fuel was considered. Although there is at first an apparent cost advantage, further analysis of performance data and operating conditions has led to the conclusion that use of this fuel would not be advantageous. While the dimensional behavior of such fuel when used in test reactors such as the MTR has been excellent it is by no means assured that the same would be true at the higher temperatures in N-Reactor. No simple fabrication process for cladding the fuel with Zr-2 is known. Further, no technique for producing a strong, high integrity bond between Zr-2 and Al-U fuel is known. Thus, the failure behavior associated with unbonded fuel elements would be a problem and the corrosion resistance of this fuel, while greatly superior to that of unalloyed uranium, is not nearly as good as that of Zr-U fuel. A potentially serious deficiency arises from uncertainty over the heat transfer situation. This occurs because in an unbonded tubular fuel element operating at a very high heat flux (about 500,000 Btu/ft² hr), the high thermal expansion coefficient of the fuel relative to the cladding would cause good thermal contact with the outer clad, and poor thermal contact with the inner clad. Thus it is uncertain whether the design heat split could be achieved and maintained. The low melting point (640°C) of Al-U fuel is a disadvantage especially in an unbonded element operating at high power density.

Uranium oxide is another fuel possibility of considerable merit, especially from the point of view of irradiation stability and corrosion resistance. However, the lack of experience with the fabrication of thin-walled tubular elements and with their performance led to preference for the Zr-U system for this application.

DECLASSIFIED

DECLASSIFIED

HW-79306-DEL
Page 10

Al-U fuel or uranium dioxide fuel would require the use of fabricated tubing for fuel assembly. The current state of the technology would require use of 35 mil tubing (or greater) for the cladding whereas in a coextruded fuel, much less cladding would be required.

Recent data on the performance of niobium-uranium alloy (10-30% uranium) in fuel elements are very promising. Good performance to burnups of 3% at temperatures up to 1000°C has been observed. This is a major advance in metallic fuel technology. If Zr-U compositions were found to be inadequate, the Nb-U fuels would be available. Although niobium costs about three times as much as zirconium and has a higher cross-section (1.1 versus 0.18 barns) the thermal conductivity is 2-3 times better than that of zirconium.

2. Target Elements

The proposed fuel design includes a thin-walled Zr-2 clad target tube as the outer component of the fuel-target assembly and a Zr-2 clad rod on the axis. Aluminum is the diluent material for the lithium target material. The compositions are 2% lithium in the tube and 3.5% lithium in the rod. The exposure levels require a 30 Gas Volume Ratio (GVR) for each component.

Conservative extrapolation of data obtained at lower temperatures than those expected for the proposed fuel indicated a reasonable probability of successful operation of the outer target (2% alloy) to a GVR of 30. Any greater exposure of this alloy might lead to problems arising from swelling and migration of tritium. This outer target is a thin-walled tube so its behavior when the core material swells is expected to be similar to that previously described for the drive element. Here, however, the tube is of larger diameter and larger radius ratio so one could expect only 1% circumferential strain in the outer cladding for 15-20% swelling under the assumption that the inner diameter remains constant. This is an unrealistic assumption, but the results indicate the relatively minor impact of swelling in a thin-walled, large diameter tube.

In the rod, it was necessary to use Al-3½% Li for the target material. This alloy will consist of two phases -- beta, the intermetallic compound LiAl, and alpha, the solid solution of lithium in aluminum. The alloys, up to 2% lithium consist only of the alpha phase. The available data on Al-Li alloy behavior indicate that the two-phase alloys swell at a higher rate and that thermal diffusion of lithium (with localized volume increases as the result) will occur if the temperature gradient exceed about 100°C per inch. Thus, one would expect the rod behavior to be intolerable if the tube behavior, mentioned above, were just adequate. However, the rod geometry provides some freedom in the geometrical design so that features which will mitigate the enhanced swelling rate can be incorporated in the design. The principal design feature currently felt to be of value in this respect is an axial hole in the target rod amounting in volume to about 10% of the target volume. This would permit the first 10% of the swelling to occur without an external effect on the clad target rod. The temperature gradient in the rod will be much less than 100°C per inch so thermal diffusion is expected to be a minor problem if it occurs at all. Recent data obtained from analysis of Li-Al rods irradiated in the KER loops have indicated negligible tritium migration after exposure to the 8 GVR level.

In order to minimize tritium migration, no bond between target and cladding is specified. The normal oxide film on aluminum is known to be an effective hydrogen and, we presume, tritium diffusion barrier. Use of an unbonded cladding means that a fabrication process other than coextrusion will be required and, since Zr-2 tubing will have to be fabricated separately, that cladding of 35 mils or greater will be required. Unbonded cladding means, generally, poorer failure behavior than in the case of a bonded system. However, the target alloy is quite corrosion resistant (essentially the same as aluminum) and is generating little heat so the failure behavior will be quite acceptable. Little radioactivity is released in any event so loop contamination should be no problem.

3. Mechanical Design

Provision of an adequate system for support and for maintenance of separation presents some problems. In addition, the need to prevent the whole element from vibrating in the process tube will probably require a different approach to support design and charging procedures. The lightness of the proposed element (it weighs about 4 lbs per foot) and the susceptibility of Zr-2 to fretting corrosion are at the heart of the problem. The "buggy-spring" type of support should be adequate for the driver tube and target rod with the fixing system currently being used. The mechanical design will be such that there are no resonant vibration frequencies in the range of frequency of the existing force. The different thermal expansion coefficients of the components will have to be accommodated. The outer support design will have to be one which does not permit vibration of the whole element in the rapidly flowing coolant. While the solution to these design problems is not immediately apparent, the successful solution of the problem is regarded as being highly probable.

Other mechanical aspects that must be recognized are (1) the need for care in handling an element in which the outer component is quite thin and relatively weak, and (2) the charge-discharge problems arising from use of a thin outer tube. The first aspect is part of the outer support design problem, discussed above. The strongest component of the element is the driver tube and it now appears the design should be one in which the charging forces are transmitted by the driver tubes.

C. Physics Calculations

Physics calculations for the fully enriched case require considerable extrapolation from base numbers that are reasonably well established for the N-Reactor lattice. Thus the physics calculations made for a fully-enriched case would have to be confirmed by experimental tests.

The removal of U-238 from the reactor will make available for parasitic capture those neutrons formerly captured in U-238 resonances. This is clearly a loss in production. In order to minimize this loss, the blackness of the fuel, including target, must be increased. This increasing blackness creates temperature coefficient and long term reactivity problems. The multiple concentric cylinder approach to the fuel design therefore requires cylinders that are transparent because of thinness but whose aggregate is black.

DECLASSIFIED

██████████

DECLASSIFIED

HW-79306-DEL
Page 12

The temperature coefficients and the long term behavior of such fuels depends on the relative amounts of target inside and outside the U-235, or vice versa. Unhampered by fuel fabrication restrictions, there is little doubt that proper amounts could be found to keep the reactivity swings within the control system strength. These exact amounts would need some experimental verification. However, the fabrication of Zircaloy jacketed fuel imposes restrictions as to minimum thicknesses of the cylinders and could therefore create a situation where the concentric cylinder approach is not the best.

Lattice physics runs made using the Flex II program, have shown that a production capability of the order of 10 to 11 milligrams of tritium per megawatt day can be obtained with the tube-driver-tube fuel concept, with a residence time of about one year. Reactivity considerations would require a fractional reactor charge-discharge of about $\frac{1}{4}$ of the core every three-four months.

Optimizing of the fuel design concept to provide maximum conversion ratio, within the bounds of engineering, manufacturing, and physics limitations will require extensive additional parametric studies. In the reference fuel design, the blackness requirements of the target elements have required the use of lithium-6 isotope. If highly enriched lithium were not available, it would not be possible to obtain the production yields indicated above.

The use of a fully enriched driver element, with separate "poisonous" target elements introduces two specific problems. The first of these is that the absence of U-238 in the fuel causes a large increase in the amount of gamma energy which is generated within the process tube and moderator. Calculations based on the reference fuel design show the following increase in total heat generation in these components, compared to the Phase I tube-in-tube fuel element.

Table I
Per Cent of Total Heat Generation Occurring In

<u>Fuel Element</u>	<u>Process Tube</u>	<u>Graphite</u>
Tube-in-Tube	0.46	4.37
Fully Enriched	1.0	6.54

The principal problem caused by this increased gamma heating would be the elevation of localized areas of the process tubes. Based on design calculations the maximum process tube temperatures, at the trunnion blocks would be about 770°F, which is about 70°F above current specified maximum operating temperatures. There are, however, elements of uncertainty in both the calculations and the specified limiting temperatures. Again experience in operating the N-Reactor may show the situation to be more favorable than can now be demonstrated. The higher graphite temperature that will also result from the increased gamma heating is not believed to be excessive although more emphasis would necessarily be placed on careful exclusion of oxidizing gases from the graphite stack.

████████████████████

DECLASSIFIED

HW-79306-DEC
Page 13

The second problem caused by the reference fully enriched design is the necessity of insuring adequate dimensional stability of the "poison" target section of the fuel element following loss of cooling incidents. Since the poison effects of the Li-Al target compensate for the excess reactivity of the fully enriched driver element, it is necessary that the poison material remain in the core, and in an adequate dimensional geometry, following all credible incidents, to meet nuclear control requirements. These nuclear control requirements for the N-Reactor are defined as "Each of the two independent safety control systems must have adequate control strength to maintain the reactor subcritical under all normal operating conditions and credible accident conditions."⁽⁶⁾ Present knowledge of the post irradiation behavior of the Zircaloy clad target elements does not permit the conclusion that the reference design could meet the above nuclear control requirement.

IV. ECONOMIC PARAMETERS

A summary of the production and economic evaluation of the fully enriched loading of N-Reactor is presented in Table No. 2. These costs are based on the fuel cycle shown in Figure 2. The production during a post 1972 year after equilibrium has been reached is based on the following:

- a) a conversion ratio of 0.85 gms Pu equivalent per MWD,
- b) a plant factor (P.F.) of 90 per cent,
- c) a fuel exposure of 100,000 MWD/T,
- d) a power level of 4000 MW, and
- e) the kilograms of neptunium and tritium generated in the reactor have not been adjusted to take into account losses during separations. All unit cost calculations and neptunium credits are based upon these unadjusted amounts of product generated.

Under the above conditions, the N-Reactor is capable of producing about 14 kgs of tritium. The neptunium production in kilograms generated (33 kgs/yr) is based on values that assume the uranium is recycled through the reactor, with 6 cycles occurring during a 12-year period. Credits are based upon a neptunium value of \$200 per gram of neptunium generated. Blending penalty and incremental separations costs for neptunium are not considered.

The fuel costs are based upon today's estimated costs that have been projected to post 1972 by reducing the costs at a rate of two per cent per year. An On-Site fuel cost of \$171 per foot of fuel element is estimated for FY 1972. The \$171 per foot of fuel element includes the 1972 estimated HAPO overhead of 16.5 per cent.

The On-Site separations costs for the driver element includes the processing of N-Reactor fuel through primary separations and UO_3 conversion, but does not

(6) HW-76930 Volume 1, "N-Reactor Hazard Summary Report."

DECLASSIFIED

DECLASSIFIED
WITH DELETIONS

HW-79306-DEL
Page 14

DECLASSIFIED

TABLE 2
ECONOMIC EVALUATION
SUMMARY

Power Level	4000
Total Pu (eq) Generated, Kgs/yr	1117
Tritium Generated, Kgs/yr	14.0
Np-237 Generated, Kgs/yr	33.0
Uranium Throughput, Orallooy Tons/yr	13.14
Li Al Throughput, Tons/yr	19.23
Product Costs (in Thousands)	
On Site Costs (Incl. 16.5% HAPO overhead)	
Fuels	
Irradiations	
Separations :	
Off Site Costs	
Fuels	
Separations	
Burnout Cost	
Total Product Costs	
Steam Credits	
Net Product Costs	
Unit Product Costs Before Steam Credits \$/gm Pu eq.	
Unit Product Costs After Steam Credits \$/gm Pu eq.	(118)
Billings to WPPSS	1,200
PAC & Equipment	1,100
Research & Development	
Transportation & Security	
Uranium	156
Li Al	153
Unit Irradiation Costs	85
*Other Costs	391
Grand Total	
Unit Total Cost \$/gm Pu eq.	(6,600)
Np Credits	
Net Product Cost with Np Credits	
Unit Product Cost with Np Credits	
Grand Total Cost with Np Credits	
Unit Cost Total with Np Credits	

*CPD Research & Development Allocated Costs

DECLASSIFIED
WITH DELETIONS

DECLASSIFIED

~~DECLASSIFIED~~
~~WITH DELETIONS~~

HW-79306-DEC
Page 16

include the costs of neptunium recovery. A cursory study indicates that the separation costs in the Redox Plant and the UO_2 Conversion Plant of the Chemical Processing Department will be in the order of 40¢ to 60¢ per gram of uranium, without depreciation charges. An average cost including the HAPO overhead of 58¢ per gram of uranium was used in this study.

The Off-Site separation costs for tritium was supplied by the AEC, Richland Operations Office as per gram of tritium in the range of 13 to 17 kilograms of tritium.

A steam credit for the post 1972 equilibrium year of \$6,700,000 per year, as established by contracted agreement between AEC and WPPSS, was used for this study.

As shown in Figure 2, the regeneration of uranium enrichment will be routinely accomplished by blending the discharged material from the reactor with material from Isotope Separations. The quantity of make-up material will be based on that necessary to replace the uranium-235 burned out and to off-set the poisoning effects of the uranium-236. The alternate path showing the flow through the isotope separations plant is to provide a process material flow in the event that the buildup of uranium-236 becomes a problem.

The burnout costs are based on data in document HAN-85315. This burnout schedule was prepared for the current AEC ten-year cost study.

At high exposures there is significant burnout of uranium in the irradiation process. For an equilibrium year, the quantity of uranium charged into the reactor is 13.14 tons per year whereas after burnout the quantity of uranium is reduced to 11.64 tons per year. The value for the final uranium enrichment includes the effects of the loss of uranium-238 in irradiation, the burnout of uranium-235 and the build-up of uranium-236. Surprisingly, the build-up of uranium-236 has an appreciable effect. For instance, the discharge enrichment not including the uranium-236 would be 92.2 per cent as compared to 89.3 per cent when the uranium-236 is included. Generally speaking, the additional burnout charges created by the uranium-236 build-up is which has a significant effect on increasing the unit cost. Despite the fact that uranium-236 has an indirect value as a precursor to the much in demand Neptunium-237, no credit is given for its presence in the discharge material.

Our present technology in regard to the behavior of uranium-aluminum matrix at high temperatures does not permit us to prognosticate it, at this time, as a good fuel candidate. Nevertheless, it is interesting to note that the use of an aluminum alloy in the driver element would reduce our off site costs by about 20 per cent. This cost reduction if all other costs are held constant would decrease unit cost by nearly of Product.

The N-Reactor is capable with a fully enriched load to produce 14 Kg tritium per year at an economically competitive price of equivalent with steam and neptunium credits.

~~DECLASSIFIED~~
~~WITH DELETIONS~~

DECLASSIFIED

HW-79306-DEL
Page 17

V. RESEARCH AND DEVELOPMENT

Operation of the N-Reactor for tritium-only production with a fully enriched uranium fuel element would represent a major departure from previous experience at Hanford. While much of the fabrication technology for such fuel elements has been developed as a part of other AEC programs, extensive research and development programs would be necessary to support such a production program in the N-Reactor. The research and development programs that would be required for a multi-product program (see HW-78864) would provide much supporting information that could be applied to a tritium-only program. Thus a tritium-only program, coming after a period of multi-product operation would not present as large a technological step as it now appears.

A. Reactor Physics

Significant physics R&D investigations will be necessary to provide fuel design data, operation characteristics, and hazards evaluations. Specific driver and target dimensions, and target composition, must be established by parametric studies to give a fuel design which provides an optimum conversion ratio; and which has satisfactory characteristics in the following areas related to safety and operability:

1. Must meet engineering limitations on heat generation and heat removal.
2. Must be capable of economic fabrication.
3. Must have sufficient base reactivity.
4. Must have satisfactory exposure transients and temperature coefficients.
5. Must meet nuclear control requirements, under both operating and accident conditions, well within the capabilities of the reactor.

The physics work necessary to accomplish these ends would include both theoretical calculations and an experimental program. The calculations would serve as the basis for fuel dimension definition in the light of production economy and hazards, and the experimental measurements would serve a check point for the calculations.

Experiments would include measurements of k_{∞} and β in the PCTR for a wet and dry lattice; and measurements of buckling and control strengths in an exponential pile for the wet and dry lattice.

As previously described, the excessive gamma heating in the moderator presents a serious operational problem with this concept. Investigations of methods to reduce the gamma heating will be made.

DECLASSIFIED

██████████ DECLASSIFIED

HW-79306-DEL
Page 18

B. Materials

1. Driver Element

As stated earlier, the technology of the driver element is, to a large extent, established. Fabrication and irradiation testing of a prototype element would be required in order to (a) scout process difficulties arising from the selection of the particular composition and geometry and (b) determine whether this fuel will perform adequately to the goal exposure required by economic and physics considerations. Additional work would largely involve process development activities in alloying and melting techniques (subject to criticality considerations), procurement of Zr-2 billet components, coextrusion, inspection, end-recessing techniques, welding and inspection. If this fuel system were found, on further analysis and testing, not to be adequate for these service conditions, other courses would have to be investigated.

Fuel design changes, such as use of two driver tubes, or fuel material changes, such as use of Nb-U alloys or UO_2 fuel would be considered as well as operation at reduced exposures or power would all be considered. A more substantial development effort would be required for these other approaches.

Experience acquired by Du Pont with the HWCTR driver elements would be almost directly applicable to this program, from casting and melting through coextrusion and inspection to irradiation performance.

2. Target Element

As with the driver element, an immediate effort would be made to assemble and irradiate prototype elements in order to confirm their presumed adequacy or to determine where design or material inadequacies exist. Because the performance of the target material is more uncertain than for the fuel and because of the lack of data on alternate target materials, a series of screening tests on alternate target materials would be started immediately. Ceramic materials, cermets, intermetallic compounds and other metallic systems would be studied from the points of view of tritium retention, dimensional stability, melting point and ease of extraction after irradiation.

Casting, melting and extrusion technology for Al-Li alloys should be adequate for this application. However, the assembly, sizing and closure of unbonded Zr-2 clad target alloys would require process development and equipment development work.

3. Mechanical Design

Extensive flow loop testing of prototype elements in conjunction with design development work on support and fixing systems would be required in order to assure a system which would not vibrate and which would not deform unduly because of the different thermal expansion behavior of the components.

████████████████████

DECLASSIFIED

HW-79306-DEL
Page 19

4. Hazards Evaluations

Testing will be necessary to determine the radioactive release characteristics of the fuel element concept following loss of cooling incidents. The rate and quantity of tritium release from the Zircaloy clad target element, as a function of fuel temperature, must be established to permit hazards evaluations.

A second problem area, as described previously, is the dimensional stability of "poison" target element following loss of cooling incidents. Since the poison effect of the Li-Al target compensates for the excess reactivity of the fully enriched driver element, it will be necessary to show that the poison material will remain in the core, and in an adequate dimensional geometry, during all credible incidents, at least sufficient to meet the nuclear total control requirements.

C. Thermal-Hydraulics

The driver element, as currently envisioned, would probably operate under conditions of sub-cooled nucleate boiling in some tubes. With proper fuel design, effects of this moderate amount of nucleate boiling on reactivity and flow stability should be minor. Analyses and tests would be necessary to determine the proper flow distribution and flow stability characteristics of the proposed fuel design. Because the majority of the heat is generated in the driver element, flow mixers would probably be required to minimize coolant temperature differences in the several coolant channels. These problems would not involve new technology and should not be difficult but developmental testing would be necessary to check out design calculations.

D. Estimate of Research and Development Costs

Necessary research and development costs for an all tritium case are estimated to be approximately \$1.6 million over the costs required to develop a multi-product technology. The costs to develop the multi-product technology have been previously estimated to be about \$2.4 million above the base plutonium-only costs, assuming prompt initiation of a multi-product program.⁽⁷⁾ Thus over and above the costs associated with plutonium-only production, a total cost of about \$4.0 million would be required to mature the capability of operating with a fully enriched fuel design, again assuming a prompt and well defined program.

The additional \$1.6 million of R&D costs are due to the much more complex tube, tube, and rod fuel element. A large part of the increase would be spent in development of the fuel design. Most of the remaining R&D funds would be expended in physics and thermo-hydraulic studies. Several significant experiments would also be necessary to thoroughly evaluate the hazards aspects of operation with the fully enriched fuel.

(6) HW-78918, "Production Studies - N-Reactor Cases 1, 20 & 24,"
October 10, 1963.

VI. CAPITAL EXPENDITURES

A firm estimate of capital expenditures associated with this program has not been made. It is anticipated, however, that the capital expenditures in excess of the amounts currently planned for the plutonium-only programs would be in the order of \$2,000,000 to \$3,000,000. These expenditures would provide for new or modified equipment made necessary for handling the higher uranium enrichment in Fuel Fabrication Shops, Reactor Plant and the Chemical Processing Plants.

VII. SCHEDULE

Figure 3 on the following page is a general schedule for moving into full tritium production. Phase 1 starts after acceptance of a preliminary proposal to begin a developmental study. A significant period, up to 18 months, will be required to prepare a comprehensive analysis and evaluation of all the various technical ramifications associated with all tritium production.

Development and testing, Phase 2, should extend to approximately three years. This is due, primarily, to the complex fuel design being considered in the all-tritium program and the need to assure safe reactor operating conditions for a vastly different fuel load.

Phase 3 will follow with materials procurement and fabrication of the first load. Phase 4, full production, will be initiated approximately $4\frac{1}{2}$ years after Phase 1 has commenced.

The above schedule is also predicted on a plutonium only base. If a decision were made to enter all-tritium production after an essentially steady-state multi-product production capability had been achieved, the $4\frac{1}{2}$ year conversion schedule could likely be reduced to approximately 3 years. In this case, both Phase 1 and 2 could be reduced based on tritium production technology developed previously for multi-product operation. In addition, the schedule could be shortened substantially should there be a sufficient demand to do so. Significantly shortening the overall conversion schedule, however, could only be achieved with some increase in overall program cost.

DECLASSIFIED

FIGURE 3

SCHEDULE FOR PHASE-IN TO ALL-TRITIUM PRODUCTION

DECLASSIFIED

VIII ACKNOWLEDGMENTS

The authors would like to acknowledge the contributions of many individuals towards the preparation of this report. Particular credits for assistance are due D. H. Curtiss, T. W. Evans, E. E. Mills, P. F. Nichols, R. V. Poe, H. C. Rathvon, J. E. Rice, R. J. Shields, H. W. Slater and R. E. Tomlinson.

D. L. Condotta
D. L. Condotta
Manager
Reactor Engineering

E. G. Pierick
E. G. Pierick
Senior Engineer
Advance Technology

DLC-EGP:fm

DECLASSIFIED

DATE

FILMED

8/22/94

END