1 of 1

HANFORD TECHNICAL RECORD

(CLASSIFICATION)

DOCUMENT NO.

HW-55910

DEL

GENERAL ELECTRIC

DECLASSIFIED

SERIES AND COPY NO.

6

DATE

May 26, 1958

HANFORD ATOMIC PRODUCTS OPERATION - RICHLAND, WASHINGTON

RESTRICTED DATA

THIS DOCUMENT CONTAINS RESTRICTED DATA AS DEFINED IN THE ATOMIC ENERGY ACT OF 1954. ITS TRANSMITTAL OR THE DISCLOSURE OF ITS CONTENTS IN ANY MANNER TO AN UNAUTHORIZED PERSON IS PROHIBITED.

TITLE

CONVERSION OF A "K" REACTOR TO SINGLE-PURPOSE
POWER RECOVERY - FEASIBILITY STUDY

OTHER OFFICIAL CLASSIFIED INFORMATION

THIS MATERIAL CONTAINS INFORMATION AFFECTING THE NATIONAL DEFENSE OF THE UNITED STATES WITHIN THE MEANING OF THE ESPIONAGE LAWS, TITLE 18, U.S.C., SECS. 793 AND 794, THE TRANSMISSION OR REVELATION OF WHICH IN ANY MANNER TO AN UNAUTHORIZED PERSON IS PROHIBITED BY LAW.

AUTHOR

R. C. Walker
E. L. Etheridge
D. F. Watson

CIRCULATING COPY

RECEIVED 700 AREA

JUN 9 1958

RETURN TO

TECHNICAL INFORMATION FILES

THIS DOCUMENT MUST NOT BE LEFT UNATTENDED OR WHERE AN UNAUTHORIZED PERSON MAY HAVE ACCESS TO IT. WHEN NOT IN USE, IT MUST BE STORED IN AN APPROVED LOCKED REPOSITORY WITHIN AN APPROVED GUARDED AREA. WHILE IT IS YOUR POSSESSION AND UNTIL YOU HAVE OBTAINED A SIGNED RECEIPT FROM CLASSIFIED FILES, IT IS YOUR RESPONSIBILITY TO KEEP IT AND ITS CONTENTS WITHIN THE LIMITS OF THIS PROJECT AND FROM ANY UNAUTHORIZED PERSON. ITS TRANSMITTAL TO, AND STORAGE AT YOUR PLACE OF RESIDENCE IS PROHIBITED. IT IS NOT TO BE DUPLICATED. IF ADDITIONAL COPIES ARE REQUIRED, OBTAIN THEM FROM THE RELATED ISSUING FILE. ALL PERSONS READING THIS DOCUMENT ARE REQUESTED TO SIGN IN THE SPACE PROVIDED BELOW.

ROUTE TO:

PAYROLL NO.

LOCATION

SIGNATURE AND DATE

RECORD

COPY

WINI for 60008 Fred JUN 24 1974
HNT for 60008 JUN 29 1974
DHC for 60008 JUN 16 1974
TNC for 60008
Fifty Boxes for 5-D LOAN

Infinite Retention

Disposal Date

Authority

Authority

DECLASSIFIED

This document consists of 21 pages, No. [redacted] of [redacted] files.

by

This document consists of 21 pages, No. [redacted] of [redacted] copies. [redacted]

Classified by 6032
Dec 19 1960
U.S. DEPT. OF JUSTICE
FBI
ALL INFORMATION CONTAINED
HEREIN IS UNCLASSIFIED
DATE 11-19-01 BY 6032

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

- MASTER

Records Center
Extra

DISTRIBUTION RESTRICTED TO U.S. ONLY

DECLASSIFIED

HW-55910
Page 2

CONVERSION OF A "K" REACTOR TO SINGLE PURPOSE
POWER RECOVERY - FEASIBILITY STUDY

I. INTRODUCTION

Somewhere in the future lies the possibility that the existing HAPQ reactors will no longer be required for the production of weapons grade plutonium. This could come about either through advances in technology or through changes in the requirements for this particular fissionable isotope as a weapons material. In any event, should these reactors no longer be utilized for plutonium production, it would be appropriate to consider the possibility of their conversion to other uses, notably that of electrical power production.

Accordingly, this study has been made with the objective of investigating the economic and technological feasibility of such conversion. However, it must be recognized that the results presented herein are based on present day technology and economic philosophy and that within the next five years we may experience considerable renovation of these criteria which could alter the conclusions of the study appreciably. The primary benefit to be gained from this preliminary study is to narrow the area of future and more detailed investigation as much as possible so that if and when such a conversion appears likely, a significant fraction of the almost infinite number of combinations of reactor and power plant parameters may be rejected at the outset.

Unfortunately, this study was initiated at about the same time that the NPR program was gaining momentum and, in addition, the Gas-Cooled Reactor Study arose during the same period. Both of these latter studies were justifiably accorded a higher priority and as a result there are some areas which would have been more fully explored under other circumstances. However, as stated above, many of these areas are readily definable, based on the work which was performed, so that future studies can be immediately directed toward the most promising combination of process parameters. A summary of the conditions considered is shown in Appendix I, page 19.

DECLASSIFIED

DECLASSIFIED

HW-55910

Page 3

II. BACKGROUND

It should be noted that several studies (1)(2)(3)(4) have previously been made to evaluate the feasibility of recirculation as a method of pile cooling and/or recovery of waste heat from the existing reactors. While it was pointed out in these studies that some technological problems exist such as demonstrated performance of a sub-atmospheric steam turbine and problems related to the containment of large volumes under negative pressure, these problems were not felt to be insurmountable; however, economic justification for either one or a combination of these schemes was shown to be somewhat nebulous. The results of these prior studies cannot be compared directly to the conclusions stated herein, inasmuch as all of these previous studies were concerned only with the feasibility of heat recovery as a by-product of weapons grade plutonium production rather than power recovery with by-product fuel grade plutonium as has been considered here. The primary differences between these two types of approaches which result in markedly different economic evaluations are:

- (1) Modifications to an existing production reactor are assumed to be government financed and therefore no allowance is made for interest on capital investment, taxes or profit while conversion to a privately owned power reactor would require approximately 15% per year capital charge.
- (2) In studies of production facilities, the credit taken for the plutonium produced is based on its value as weapons material which is several times higher than the value which must be used in calculating the credit obtainable from a privately owned power reactor which is producing only fuel grade plutonium.
- (3) Fabrication and reprocessing costs are generally of the order of 20% higher for private ownership than for comparable cases of government ownership.

-
- (1) HW-30907-RD, Economic Evaluation of Recirculation as a Method of Pile Cooling, A. B. Carson, R. H. Purcell and L. H. McEwen, April 7, 1954, Secret - Red Label.
 - (2) HW-38968, Utilization of Waste Heat from Hanford Reactors for Production of Marketable Power, A. J. Karnie, G. R. Hosack and H. S. Davis, September 23, 1955, Secret.
 - (3) HW-42523, Preliminary Study - Heat Recovery from Existing Reactors, W. J. Mundt and E. L. Etheridge, May 1, 1956, Secret.
 - (4) HW-45471, Economic Study of Power Recovery from Hanford's Reactor Waste Heat, E. L. Etheridge and W. J. Mundt, June 4, 1957, Secret.

DECLASSIFIED

HW-55910

Page 4

III. CONCLUSIONS AND RECOMMENDATIONS

The most striking result of this study is that, under the existing criteria, there are a large number of possible operating parameters which can be disregarded without further consideration. As will be shown in detail in the body of this report, it is not now practicable to consider use of cluster-type elements which are normally considered to be one of the most desirable types for a power reactor.

Further, it appears that optimum power recovery will provide approximately 180 - 200 MW of saleable power from a "K" Reactor at a net cost of 12.5 - 13.0 mills/kwh for a goal exposure of 1000 MWD/T. (See Figures 3 - 6, Inclusive, Pages 16 and 17). The capital investment required in this case would be of the order of \$370/kw(net). If exposures could be extended to 2000 MWD/T, the resulting power cost would drop to 10.5 - 11.0 mills/kwh; however, the latter exposure is overly optimistic based on present technology but is mentioned to illustrate the significant manner in which power costs are improved by increasing exposure. While these power costs are approximately 3 to 3.5 times greater than the present value of electrical energy in this locality⁽⁵⁾ this capacity represents approximately 60 - 70% of the current HAP0 power demands from the Northwest Power Pool. Therefore, the combined effect of shutting down the other older reactors and the generation of power from a "K" Reactor would be a net gain to this pool of 450 - 500 MWe which would then become available for other industrial uses. While it is not possible to produce this power in competition with government financed hydro-electric stations, either from the standpoint of unit cost or over-all plant efficiency, the power produced would provide considerable relief during periods of high demand and, of course, an important by-product would be fuel grade plutonium which should become a marketable commodity within the next few years.

It should be recognized that these results are based on technology which could very easily become obsolete within a very few years. Therefore, we could conclude that improved fuel element fabrication techniques, development of organic coolant technology, improved heat recovery equipment, etc. should tend to lower the resultant net power costs while the value of power has a rising tendency. However, these same technological advances also work to the advantage of any new power reactor and since it is also technologically feasible to construct a new power reactor which would be economically competitive with any "K" conversion scheme⁽⁵⁾, the incentive for further study would more logically be directed toward new facilities which are designed specifically for power production.

(5) HW-55579, Unit Cost Tables - NPR, W. J. Dowis and H. R. Kosmata, April 3, 1953, Secret.

IV. DISCUSSION OF PROPOSED PROCESS CONDITIONS

Essentially, there were no limitations placed on this study, per se, other than those listed in the following paragraph. However, several limitations which became apparent and which confined the effort to a more specific range are discussed briefly in the paragraphs following:

A. BASIC ASSUMPTIONS

1. There is no appreciable demand or market for weapons grade plutonium, at least insofar as the HAPO reactors are concerned.
2. An existing "K" Reactor would be available to an appropriate power generating agency on an as is, no charge, basis.
3. All modification costs would be borne by the power generating agency. Private financing rates of 15%/yr capital charge would apply.
4. Any by-product plutonium would be utilized as fuel and would have a market value of \$12/gram.

B. REACTIVITY EFFECTS UPON LOSS OF PILE COOLANT

The current attitude of the Atomic Energy Commission is that any new reactor shall not be overmoderated; i.e., there shall be a loss of reactivity upon loss of pile coolant. Conversion of a "K" Reactor to power production by a private power generating agency would, in effect, be a new reactor. Therefore, a strict interpretation of the above criteria would prohibit further consideration of such conversion since "K" piles are presently overmoderated even with solid slugs and the only way to obtain relief from this condition is to either introduce more fuel into the same lattice or remove some of the moderator from the lattice cell. Therefore, a more lenient interpretation of the above criteria was taken by concluding that it should be permissible to operate the "K" Reactors as power reactors if the conversion did not result in a larger reactivity effect from loss of coolant than would be experienced while operating as production reactors. Accordingly, the reactivity gain (cold, clean) due to water loss from a "K" Reactor when fully loaded with the "C" type I & E slugs*

*1.474" O.D. x 0.375" I.D. x 8.965" long.

DECLASSIFIED

HW-55910

Page 6

was calculated and set as limiting for all cases which were subsequently considered. Details of this analysis are discussed in the following paragraph but it can be noted here that this was a very confining criteria; in fact, it was shown that, under these conditions, it is not presently feasible to consider any extended surface fuel element for use in a "K" Reactor. This then established the I & E slug as having the minimum uranium-to-graphite ratio characteristics. An improvement to this slug from the standpoint of nuclear safety would be reversion to the cored or solid fuel element. This, however, would also imply much lower goal exposures which has a very undesirable effect on the net power costs. Therefore, the fuel element which is considered to be very near optimum for power conversion is the same element which is now being planned for production use.

C. FUEL ELEMENT

As a start, it was decided to set the existing process tube O.D. as limiting, assume the use of the "C" Type I & E fuel element and to vary the process tube material, I.D. and inlet coolant temperature. Based on the reactivity criteria which had previously been determined, this showed that the tube wall thickness could not be less than about 0.050" with a 6063* aluminum tube or less than about 0.045" with a Zircalloy-2 tube. In an attempt to introduce more fuel into the lattice, an alternate I & E element, which has the same external dimensions but thinner can walls, was evaluated under the same conditions. This analysis showed that the tube wall thickness could not be less than about 0.035" with a 6063 tube or less than 0.030" with a Zircalloy-2 tube. The resulting power costs from this analysis showed a slight advantage for the alternate fuel element but probably not enough to warrant the change.

Extended surface elements are usually considered to be a more desirable fuel configuration for power producing reactors since they are generally capable of achieving greater exposures at higher power densities. Inasmuch as a "K" Reactor is presently overmoderated to a significant extent, the use of a cluster element in the same lattice would only serve to amplify this problem. Therefore, it was decided to evaluate the effect of coring the reactor to accept a process tube of 2.120" O.D. which would have the two-fold effect of reducing the amount of graphite in the lattice while providing enough space in the tube for a cluster element which could potentially operate at a higher temperature. In this evaluation, the area of fuel in the lattice became a function of the tube wall thickness and the number of elements in the cluster since it had previously been decided

*Formerly designated 63S.

DECLASSIFIED

HW-55910

Page 7

that the individual elements in the cluster should be spaced to allow for a double volumetric expansion without contacting an adjacent element or the process tube wall. This magnitude of expansion is somewhat arbitrary but is based on the reaction of uranium with elevated temperature ($>180^{\circ}\text{C}$) water and is the same criteria that was followed in sizing the cluster elements in the recent NPR Study⁽⁷⁾. The results of this analysis indicated that the use of cluster elements would increase the reactivity change on loss of water in the order of 2 - 4 times the present amount and for this reason a quantitative evaluation of power costs was not made.

In this study, only metallic uranium fuel was considered since an oxide element would occupy more than twice as much of the available flow area as the metallic element. While this would undoubtedly improve the reactivity effects upon loss of pile coolant, very little area would be available for the flow of the coolant which would imply very high pressure drops with the over-all result of significantly increasing the net power cost due to the reduction of thermal efficiency. Moreover, no attempt was made to evaluate solid fuel elements since experience has shown this to be a limit on exposure and as stated above, every attempt is normally made to extend exposure in a power reactor concept.

D. PROCESS TUBES

Although there is generally a strong tendency toward the use of Zircalloy-2 for the process tubes in an elevated temperature concept, the results of this study indicate a slight advantage for a 6063 aluminum tube. However, this advantage could easily be reversed in the next few years, particularly if the temperature limitations imposed in this study could be relaxed. The reason for such a reversal could arise from one or more of the following points:

1. Fabrication techniques for zirconium tubing are advancing rapidly and further development effort is being concentrated on this material due to its many possible applications.
2. Zircalloy-2 has a lower absorption cross-section to thermal neutrons. ($\Sigma A = .008 \text{ cm}^{-1}$ for Zr-2 compared to $\Sigma A = .013 \text{ cm}^{-1}$ for 6063 aluminum).
3. It is presently considered that Zr-2 is the best potential material for elevated temperature concepts⁽⁸⁾.

(7) Private communication with G. L. Locke.

(8) HW-50613, An Evaluation of Zirconium Alloys for Hanford Uses, D. E. Johnson, June 5, 1957, Unclassified.

DECLASSIFIED

HW-55910
Page 8

4. The nature of a power reactor (high temperature, long exposure, etc.) inherently excludes consideration of materials which would increase the frequency of outages for such maintenance as tube replacement which could be a significant operating expense when using aluminum tubes.

E. PROCESS COOLANT

Demineralized water was selected as the pile coolant. A wide variety of organics have recently been recognized as potential coolants, particularly in high temperature recirculating concepts since a much lower operating pressure can be utilized due to the low vapor pressure of organics. However, organic technology has not yet been developed sufficiently to permit a very realistic application to a study such as this. It is of interest to note, however, that the use of an organic coolant will result in somewhat lower reactivity gains upon loss of coolant.

The maximum water temperature was set at 180°C for all cases in which the fuel area exceeded one-half of the coolant channel. As mentioned previously, this limit does not come about because of any sharply defined change in this reaction rate but is considered to be a reasonable limit based on known phenomena. Inasmuch as there has been insufficient data developed to date which would tend to relax this limit, this criteria was used as the basis for this study although higher permissible outlet temperatures would improve the efficiency of the heat recovery cycle.

V. DESCRIPTION OF POWER RECOVERY SYSTEM

With a maximum reactor water temperature limitation of 180 C imposed on the power recovery system, the proposed power generating plant is automatically established as a low pressure, saturated steam power system. Optimization of the power recovery system resolves down to determining the reactor inlet temperature and coolant flow to obtain the maximum net power output with the lowest capital and operating costs.

As one of the basic criteria, it was assumed that only a recirculating cooling system would be considered for this study. Power recovery from a reactor with the present "single pass" cooling system has been shown to be economically unfeasible, primarily because a sub-atmospheric or atmospheric steam pressure power system must be employed.⁽⁴⁾ Even with sub-atmospheric steam pressures, as much as 40 percent of the reactor heat in a single pass system must be diverted directly to the river because of its "low grade" heat. The present "K" water treatment would have to be improved considerably to provide a water

(4) HW-45471, op. cit.

quality which would allow long term exposure (approximately 1000 MWD/T or longer) of aluminum jacketed fuel element without encountering serious corrosion and rupture problems. The treatment costs required to attain this quality would be prohibitive for use in a single pass cooling system. Therefore, a recirculating cooling system with cleanup facilities to maintain high quality water would prove more economical for a "K" power recovery plant.

By converting to a recirculating cooling system, it is possible to vary the reactor inlet temperature and reactor flow rates in order to obtain the "grade" of heat that can most economically be extracted for power recovery. In the "J" Reactor design study a temperature relationship

$$T_B = 0.8 T_{m0} + 0.2 T_I$$

where

T_B = Bulk outlet temperature

T_{m0} = Outlet temperature of maximum performance tube

T_I = Inlet temperature

was derived which would provide for possible flow instrumentation errors when utilizing a high operating efficiency without exceeding the maximum temperature limit. (9) Using this temperature relationship, optimum reactor inlet temperatures and coolant flow rates were determined for five steam pressures for a 250 MWe gross power recovery system. The results are plotted on Figure 1, page 10.

Some interesting facts are shown on this graph. On the left of the minimum point of a turbine pressure curve, any power recovery system selected would have to provide dump heat exchangers to dissipate a portion of the reactor heat. This amount of "low grade" reactor heat would be equal to that particular power level minus the minimum power level for that turbine pressure curve. As an illustration, suppose the reactor conditions were set at 120 C inlet and 168 C bulk outlet temperature with a 25 psig turbine pressure power recovery system. Then for a 250 MWe (gross) power plant, the reactor power level would be 1790 MWh. The amount of reactor heat to be dumped to the river via water-to-water heat exchangers would be 1790 minus 1400 or 390 MW. The size of the dump heat exchangers would also have to be large enough to handle the entire reactor coolant flow. These calculations are based on a minimum 10 F temperature approach in the heat exchanger equipment. For larger temperature approaches, the quantity of low grade heat to be dumped would be greater and for smaller approaches, heat exchanger costs would be prohibitive.

10 X 10 TO THE CM. 359.14
KEUFFEL & ESSER CO. MADE IN U.S.A.
K-4

DECLASSIFIED

625

DECLASSIFIED

HW-55910

Page 11

On the right side of the minimum point of the turbine pressure curves, the steam power cycle output remains constant, but more efficient heat transfer can be obtained because of higher temperature drive in the heat exchangers. Therefore, heat exchanger costs can be reduced because less surface area is required.

Reactor coolant flow rates are also shown on Figure 1. It is seen that flow rates increase directly with the turbine pressure. Consequently, in order to increase thermal efficiencies by taking advantage of a higher steam turbine pressure, pumping costs in the primary loop must be sacrificed. This penalty will more than offset the gains made through reduced piping and equipment sizes in the steam plant.

On Figure 2, gross and net power output for representative turbine pressures are plotted against the reactor power levels. It is seen that the net power output begins falling off sharply above 300 MWe due to increased flow resistance in the primary loop. Since the "K" reactors were originally designed for single pass cooling with a large temperature rise across the reactor, the flow annuli of the process tubes are necessarily small. Coring out the fuel channel to permit installation of larger tubes with increased flow rates has been shown to be technologically unfeasible; therefore, the net power output of a "K" reactor power plant is governed by primary loop pumping costs.

A. STEAM POWER CYCLE

The assumptions used to establish steam rates and plant efficiencies in the power recovery system are:

1. Saturated steam.
2. Negligible steam pressure drop from heat exchanger to the turbine stop valves.
3. Steam turbine efficiency - 80% Rankine.
4. Turbine exhaust pressure - $1\frac{1}{2}$ " Hg absolute.
5. Temperature approach in heat transfer equipment - 10 F minimum.
6. Condensate temperature - 92 F.
7. Reactor temperature relationship $T_B = 0.8T_{mo} + 0.2T_i$.
8. Condenser cooling water inlet temperature - 60 F.

Using the above criteria, power recovery systems were calculated for 5, 10, 15, 20 and 25 psig steam pressures for non-extraction condensing turbines. The pertinent data from this analysis are shown in Appendix II, page 21.

DECLASSIFIED

826

FIGURE 2 - POWER OUTPUT VERSUS REACTOR POWER LEVEL

DECLASSIFIED

HW-55910
Page 13

B. PLANT LOAD

The plant supporting facilities power demand is relatively negligible compared to the plant pumping power demand. Rough estimates of the plant supporting facilities power loads were calculated and are outlined in Table I for three power recovery station sizes.

TABLE I
PLANT SUPPORTING FACILITIES POWER LOAD

FACILITY	PLANT GROSS POWER OUTPUT		
	200 MW	300 MW	400 MW
Reactor and Area (Includes shops, offices, 165 Bldg. and reactor)	2000 KW	2000 KW	2000 KW
Existing Water Plant	250 KW	250 KW	250 KW
Demineralization Plant	200 KW	210 KW	220 KW
Power Plant (Instrumentation, vacuum pump, etc.)	45 KW	65 KW	95 KW
TOTAL	2495 KW	2525 KW	2565 KW

In contrast to the above values, the plant pumping power load varies from approximately 23,000 KW for 200 MW gross electrical output to approximately 80,000 KW for 400 MW gross electrical plants. Ratio of the power demand of the primary loop pumps and the condenser cooling water pumps is about equal for a 200 MW electrical plant whereas for a 400 MW electrical plant, this ratio increases to approximately 4:1.

VI. DESCRIPTION OF REQUIRED PLANT MODIFICATIONS

In order to effect a conversion of a "K" reactor for power recovery, there are several major modifications and plant additions which would necessarily be required. While no attempt was made in this study to develop detailed drawings of contemplated modifications, this aspect was examined in sufficient detail to develop items of cost which were considered in the over-all economic evaluation. Following is a summary of these anticipated modifications which is supplemented by a sketch of possible building locations in Appendix V, page 24.

DECLASSIFIED

HW-55910
Page 14

A. 190-K BUILDING

The existing piping from 190-K to 105-K must be modified to provide for thermal expansion. New secondary pumps must be installed to provide the head and flow required for the power conversion. Existing motors, flywheels and drives may be re-used. Primary pumps would remain as installed to provide emergency flows. Existing instrumentation and control could be re-used, with minor modifications.

B. HEAT EXCHANGER AND TURBINE BUILDING

A possible site for the power recovery buildings is directly west of the 105 Building, south of the transfer area tracks. In the case of the KE reactor, the return process water lines can be routed to 190 KE through the cross-over tunnel.

The existing 60" raw water lines from the 181 pump houses would be connected to the power building to provide a portion of the required condenser cooling water. Additional cooling water would be provided from a river pump house addition and additional pumps. A portion of the pumping power could be recovered by routing the condenser effluent through turbines attached to the drive shafts of the new pumps.

C. FRONT FACE

The front face will generally require little replacement of piping since it was designed to 400 # ASA standards; however, detail examination of each type of pipe run would be required. Alternate back-up cooling for horizontal rod and thermal shield cooling would have to be provided.

D. REAR FACE

Existing rear face cross headers may be re-used, but risers and downcomer must be replaced. Adequate expansion joints must be provided for each cross header-riser connection. Existing cross header and drain riser valves must be replaced for the pressures and temperatures considered in the subject cases.

The thermal shield drain must be connected to the existing 12" process sewer line which drains the drain riser and biological shield cooling drains.

E. PURGING

Since purging may be required for the process tubes, each cross header must be purged and flushed separately to prevent contamination of the primary loop.

DECLASSIFIED

HW-55910

Page 15

To purge during operation, two drain risers would be provided on the rear face with special diversion valves which close the riser drain after the relief riser drain is open. Special PRV's and desuperheaters would be required to maintain the same pressure in the drain risers as in the main risers, and still provide drainage to the process sewer. Separate purge lines will be required to each end of each front cross header.

F. BACK-UP COOLING

The existing back-up turbine-generators and tie-ins are adequate to provide power for reactor cooling after conversion to recirculation.

G. INSTRUMENTATION

Existing front face venturis and orifices would possibly be reusable with minor modifications. Existing Panellit gages are suitable for the pressures considered in the cases studied. Rear face thermocouples and associated instrumentation would have to be replaced or readjusted to the applicable ranges.

VII. ECONOMIC EVALUATION

As previously stated, it appears that optimum power costs for the "K" conversion described would result in power costs of about 12.5 - 13.0 mills/kwh for a goal exposure of 1000 MWD/T when using I & E fuel elements. A further breakdown of this cost for a representative case is shown in Appendix III but it is of interest to note that the primary components are approximately:

Fuel Costs	4.6 mills/kwh
Operating & Maintenance	2.0 mills/kwh
Amortization of Capital Investment	<u>6.2 mills/kwh</u>
TOTAL	12.8 mills/kwh

Representative trends in power cost as a function of the net amount of saleable power and for various combinations of fuel element, process tube and turbine pressure are shown on Figures 3 - 6, inclusive and a detailed breakdown of estimated capital costs for a representative conversion scheme is shown in Appendix IV, page 23.

10 X 10 TO THE CM. 359.14
K. E. KLUFFEL & ESSER CO. BELL, N. J.

DECLASSIFIED

HW-55910
Page 17

FIGURE 5

FIGURE 6

DECLASSIFIED

HW-55910
Page 18

VIII. ACKNOWLEDGEMENT

Appreciation is expressed to C. A. Mansius of Design Analysis for the reactor physics data which was necessary for the completion of this study.

R. C. Walker
Reactor Modification Design

E. L. Etheridge
Reactor Modification Design

D. F. Watson
Reactor Modification Design

RCW:ELE:DFW:dp

APP
"K" POWER CONVERTERS

FUEL ELEMENT		PROCESS TUBE			Bu Go Out Tem
Type	Can Mat'l	Material	O.D. (In.)	Wall (in.)	
"C" I&E	Al	1100 Al	1.806	0.063	7
"	"	6063 Al	"	0.020	
"	"	"	"	0.050	
"	"	"	"	0.080	
Alt. I&E	"	"	"	0.020	
"	"	"	"	0.050	-
"	"	"	"	0.080	
"C" I&E	"	Zr-2	"	0.010	
"	"	"	"	0.030	
"	"	"	"	0.050	
Alt. I&E	"	"	"	0.010	:
"	"	"	"	0.030	
"	"	"	"	0.050	
7 Ele. Cluster	Zr-2	"	2.120	0.050	
"	"	"	"	0.150	
"	"	"	"	0.250	
"	Al	"	"	0.050	
"	"	"	"	0.150	
"	"	"	"	0.250	
4 Ele. Cluster	Zr-2	"	"	0.050	
"	"	"	"	0.150	
"	"	"	"	0.250	
"	Al	"	"	0.050	
"	"	"	"	0.150	
"	"	"	"	0.250	
3 Ele. Cluster	Zr-2	"	"	0.050	
"	"	"	"	0.150	
"	"	"	"	0.250	
"	Al	"	"	0.050	
"	"	"	"	0.150	
"	"	"	"	0.250	
19 Ele. Cluster	Zr-2	"	"	0.050	
"	"	"	"	0.150	
"	"	"	"	0.250	
"	Al	"	"	0.050	
"	"	"	"	0.150	
"	"	"	"	0.250	

NDIX I
ON - SUMMARY OF CASES

k lant let p(C)	AREAS (In.)			PERCENTAGE DISTRIBUTION			Reactivity Gain on Water Loss (ih)
	Fuel	Can	Coolant	Fuel	Can	Coolant	
95	1.325	0.271	0.571	61.2	12.5	26.3	775
80	"	"	0.804	55.2	11.3	33.5	1003
"	"	"	0.640	59.3	12.1	28.6	802
"	"	"	0.482	63.8	13.0	23.2	575
"	1.422	0.174	0.804	59.3	7.2	33.5	854
"	"	"	0.640	63.6	7.8	28.6	661
"	"	"	0.482	68.4	8.4	23.2	479
"	1.325	0.271	0.859	54.0	11.0	35.0	1057
"	"	"	0.748	56.5	11.6	31.9	892
"	"	"	0.640	59.3	12.1	28.6	735
"	1.422	0.174	0.859	57.9	7.1	35.0	914
"	"	"	0.748	60.7	7.4	31.9	784
"	"	"	0.640	63.6	7.8	28.6	647
50	1.306	0.223	1.675	40.7	7.0	52.3	1197
"	1.042	0.201	1.359	40.1	7.7	52.2	1767
"	0.806	0.178	1.077	39.1	8.6	52.3	2183
"	1.201	0.328	1.675	37.5	10.2	52.3	1485
"	0.949	0.294	1.359	36.5	11.3	52.2	2007
"	0.725	0.259	1.077	35.2	12.5	52.3	2413
"	1.158	0.158	1.888	36.2	4.9	58.9	1942
"	0.926	0.142	1.533	35.6	5.5	58.9	2447
"	0.721	0.125	1.215	35.0	6.1	58.9	2796
"	1.083	0.233	1.888	33.8	7.3	58.9	2210
"	0.860	0.208	1.533	33.1	8.0	58.9	2685
"	0.662	0.184	1.215	32.1	9.0	58.9	3026
"	1.122	0.134	1.948	35.0	4.2	60.8	2164
"	0.871	0.119	1.611	33.5	4.6	61.9	2825
"	0.679	0.105	1.277	32.9	5.1	62.0	3131
"	1.058	0.198	1.948	33.0	6.2	60.8	2401
"	0.815	0.175	1.611	31.3	6.8	61.9	3053
"	0.630	0.154	1.277	30.6	7.4	62.0	3359
"	1.201	0.361	1.642	37.5	11.3	51.2	1419
"	0.944	0.323	1.334	36.3	12.4	51.3	1976
"	0.719	0.284	1.058	34.9	13.8	51.3	2377
"	1.037	0.525	1.642	32.4	16.4	51.2	1960
"	0.800	0.467	1.334	30.8	17.9	51.3	2451
"	0.594	0.409	1.058	28.8	19.9	51.3	2815

DECLASSIFIED

DECLASSIFIED

HW-55910
Page 20

APPENDIX I (CONTINUED)

1. Coolant - H₂O
2. Maximum Graphite Temperature - 700 C
3. "C" Type I & E 1.474" x 0.375" x 8.965" canned;
1.385" x 0.481" x 8.325" bare
4. Alternate I & E 1.474" x 0.375" x 8.965" canned;
1.414" x 0.435" x 8.325" bare
5. 1100 is new designation for 2S Al
6063 is new designation for 63S Al

DECLASSIFIED

HW-55910
Page 21

APPENDIX II
POWER PLANT DATA

STEAM PLANT DATA	TURBINE PRESSURES (psig)				
	5	10	15	20	25
Reactor Temperature, C					
Inlet	110	115	120	125	130
Outlet	166	167	168	169	170
Reactor Flow, gpm/kwe	0.422	0.436	0.464	0.498	0.516
Steam Rate, lbs/kw-hr	20.95	19.60	18.60	17.80	17.20
Cooling Water Flow, gpm/kwe	1.890	1.760	1.656	1.580	1.520
Gross Plant Efficiency, %	14.9	15.8	16.5	17.2	17.8
HEAT TRANSFER DATA					
1. Preheater Heat Transfer Coefficient					
U, Btu/hr/°F/ft ² /ft	480	480	480	480	480
Temperature Drive (LMTD), F	61.2	63.5	66.1	70.9	71.3
Surface Area, ft ² /kwe	0.0895	0.0851	0.0832	0.0812	0.0829
2. Steam Generator Heat Transfer Coefficient					
U, Btu/hr/F/ft ² /ft	900	900	900	900	900
Temperature Drive (LMTD), F	39.9	37.5	33.0	32.8	31.1
Surface Area, ft ² /kwe	0.555	0.546	0.572	0.546	0.563
3. Condensers Heat Transfer Coefficient					
U, Btu/hr/F/ft ² /ft	600	600	600	600	600
Temperature Drive (LMTD), F	18.9	18.9	18.9	18.9	18.9
Surface Area, ft ² /kwe	1.89	1.71	1.61	1.53	1.48

SUMMARY OF ESTIMATED COST

GOAL EXPOSURE	MWD/T	500		
REACTOR RATING	MWth	1210 1120	1810 1680	
CAPITAL INVESTMENT	\$ x 10 ⁻⁶	47.166 47.213	72.006 72.930	1
ANNUAL CAPITAL CHARGE	\$/yr x 10 ⁻⁶	7.075 7.082	10.801 10.940	
NET ANNUAL FUEL COST	\$/yr x 10 ⁻⁶	9.55 8.87	14.00 13.03	
ANNUAL OPERATING COST	\$/yr x 10 ⁻⁶	3.287 3.270	3.403 3.480	
TOTAL ANNUAL COST	\$/yr x 10 ⁻⁶	19.912 19.222	28.204 27.450	
GROSS POWER	MWe	200	300	
NET SALEABLE POWER	MWe	140.32 139.12	198.72 193.04	2 2
NET POWER COST	mills/kwh	15.8 15.8	16.2 16.2	
INVESTMENT/CAPACITY	\$/kw (net)	336 339	362 378	

* Process Tube
 Fuel Element
 Bulk Outlet Temp.
 Plant Utilization Factor

NOTE: Where two figures are
 turbine pressure and

IX III

FOR REPRESENTATIVE CASE*

	1000			2000		
	1210	1810	2420	1210	1810	2420
	1120	1680	2240	1120	1680	2240
97.712	47.166	72.006	97.712	47.166	72.006	97.712
00.956	47.213	72.930	100.956	47.213	72.930	100.956
14.657	7.075	10.801	14.657	7.075	10.801	14.657
15.140	7.082	10.940	15.140	7.082	10.940	15.140
18.58	5.57	8.04	10.56	3.38	4.77	6.20
17.24	5.20	7.50	9.83	3.17	4.47	5.78
3.520	3.287	3.403	3.520	3.287	3.403	3.520
3.686	3.270	3.480	3.686	3.270	3.480	3.686
36.757	15.932	22.244	28.737	13.242	18.974	24.377
36.069	15.552	21.920	28.659	13.522	18.890	24.609
400	200	300	400	200	300	400
13.36	140.32	198.72	243.36	140.32	198.72	243.36
24.48	139.12	193.04	224.48	139.12	193.04	224.48
7.3	13.0	12.8	13.5	11.2	10.9	11.4
8.3	12.8	13.0	14.6	11.1	11.2	12.5
402	336	362	402	336	362	402
452	339	378	452	339	378	452

DECLASSIFIED

6063 Al w/0.050" Wall
 "C" Type I & E Element
 180 C
 80%

given, upper figure is for 15 psig
 lower figure is for 25 psig turbine pressure

DECLASSIFIED

HW-55910

Page 23

APPENDIX IV

"K" REACTOR POWER STUDY COST ESTIMATE
300 MW, 15 PSI TURBINE PRESSURE, ALUMINUM TUBES

<u>ITEM</u>	<u>BASIS FOR ESTIMATE</u>	<u>COST</u>
Preheaters	26,400 ft ²	\$ 691,000
Heat Exchangers	172,000 ft ²	4,506,400
Heat Exchanger Structure	600 yd ³	60,000
Condensers	460,000 ft ²	3,864,000
Feed Pumps	550 HP	49,500
Condenser Cooling Water Pumps	11,300 HP	1,175,000
Pump House Structure	258,000 GPM	1,223,000
Primary Pumps	31,200 HP	3,120,000
Turbine Generators	300,000 KW	27,000,000
Switch Gear	300,000 KW	3,900,000
Instrument & Control	300,000 KW	600,000
Power Building Structure	600,000 ft ³	1,500,000
Power Building Crane	---	100,000
Piping to and from River	258,000 GPM	516,000
Water Treatment	139,200 GPM	1,392,000
Rear Face Piping	---	1,160,000
Piping to and from Heat Exchangers	139,200 GPM	836,000
190-K Modifications	---	300,000
105-K Modifications (Inst.)	---	400,000
New Aluminum Tubes	---	<u>945,000</u>
	SUB-TOTAL	<u>\$53,337,900</u>
	10% Design, 15% Indirects, 10% Contingency	<u>18,668,270</u>
	TOTAL	<u>\$72,006,170</u>

DECLASSIFIED

APPENDIX V

Partial Plot Plan of 100-K Showing Possible
Location of Power Conversion Buildings

**DATE
FILMED**

10/26/93

END