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TECHNICAL BASES
U-233 PRODUCTION STUDY
GROUP V

11

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TECHNICAL BASES
U-233 PRODUCTION STUDY
GROUP V

W. K. Woods
Research and Engineering
Irradiation Processing Department

Classification Cancelled and Changed To

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By Authority of SE Gydesen
CG-PR-2, 4-13-94
By DK Hanson, 4-17-94
Verified By James M. Miley, 4-18-94

June 9, 1964

HANFORD ATOMIC PRODUCTS OPERATION
RICHLAND, WASHINGTON

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TECHNICAL BASES
U-233 PRODUCTION STUDY
GROUP V

Reference: HW-80289 REV, "Production of Clean U-233 -
Process Parameters and Limits," L. W. Lang,
et al., January 31, 1964.

I. SCOPE

"Group V" is the designation assigned locally to the fifth of a series of recent U-233 production studies requested by the Division of Production. The scope of this study is given in a teletype from F. P. Baranowski to J. E. Travis, which was sent on May 28, 1964, immediately before the Memorial Day week-end and reported to General Electric on June 1, 1964. The text is as follows:

"DRD has just advised that clean U-233 for seed and blanket program is wanted at early dates, as follows:

<u>Quantity</u>	<u>Delivery Dates</u>
160 kg	April-July 1965
40 kg	July-September 1965

Both batches would be requested at 3 to 5 ppm of U-232.

"The DRD Branch requesting this material insists the dates are important. However, approval for production program will be via staff paper route, and authorization to proceed may not be available until late June.

"Considering these circumstances, please advise: (a) portions of above quantities your site could deliver as nitrate by above dates; (b) schedules on which you could deliver half of the quantities; (c) schedules on which you could deliver the full quantities; (d) pre-authorization steps recommended to expedite program. Please provide schedules that could be reasonably guaranteed, since they could become commitments. Consider possible difficulties in obtaining suitable thorium oxide from off-site, relatively limited experience to date in making clean U-233, separations problems if short cooling is used, separation plant campaigning problems, and shortage of capital funds.

"Reply requested by June 5."

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The immediate purpose of this memorandum is to record the technical assumptions used in the study in order to provide a basis for cost evaluations. The general results have been reported by letter from A. B. Greninger to J. E. Travis, June 5, 1964.

II. SUMMARY

Tabular values are for nominal 200 kg of U-233. (Parenthetical values are for nominal 100 kg of U-233.)

	<u>1 K Reactor</u>	<u>4 Small Reactors</u>	<u>Total</u>
U-233, kg	82 (41)	136 (76.5)	218 (117.5)
U-232/U-233, ppm	5.0 (5.0)	2.9 (2.9)	3.8 (3.8)
ThO ₂ , tons	90 (45)	148 (83)	238 (128)
E-metal, tons	485 (240)	800 (450)	1285 (690)
Natural uranium, tons	-725 (-360)	-1360 (-765)	-2085 (-1125)
Pu in E, kg	335 (165)	465 (260)	800 (425)
Pu in natural, kg	-425 (-210)	-690 (-390)	-1115 (-600)
Total Pu	-90 (-45)	-225 (-130)	-315 (-175)

Notes:

tons E/kg U-233
tons natural/ton E
gms Pu/ton E*
gms Pu/ton natural*

K Core

5.9
-1.5
690
587

Small Core

5.9
-1.7
582
509

* Values provided by G. C. Fullmer, except that values provided by Fullmer for E-metal were increased by 3% so that results would be consistent with results shown for Case VII of HW-81870.

III. GENERAL ASSUMPTIONS

Certain balances must be made between low cost and early delivery. The author established that the more economical loadings in the fringes of the reactors could not be considered if an attempt were being made to produce U-233 in a hurry, and attention was paid only to loadings in the central core of the reactors. On the other hand, I also established that we could not afford to irradiate enriched uranium (E-metal) for less than its full term; thorium irradiations are to extend through a cycle defined as the time required to form 6% Pu-240 in plutonium formed in E-metal.

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The irradiation time for E-metal in the core of a small reactor at current neutron flux is 85 operating days. If thoria is irradiated for this length of time the contaminant level in the U-233 will be about 7 ppm, which is too high. Hence, irradiate two charges of thoria during one E-metal irradiation, for a contaminant level in U-233 of 2.9 ppm and a product concentration of 930 g/T. Similarly, irradiate two charges of thoria during one E-metal irradiation in the core of a K Reactor, for a contaminant level in U-233 of 5.0 ppm and a product concentration of 925 g/T.

It is probable that thoria densities will only average 7.5 gms/cc instead of the 8.5 gms/cc assumed in the reference document. This effect was allowed for in calculations related to the small reactors, but disregarded for the K Reactors.

The reference document discusses production of U-233 containing a contaminant level of 1 ppm. Since Group V studies involve contaminant levels 3 to 5 times greater, with corresponding less-frequent reloadings of thoria, assume that reactor productivity is comparable to that reported in the reference document for reactors equipped to charge and discharge thoria while operating.

Comparing Case 3 with Case 2 and Case 9 with Case 8 of the reference document leads to a value of $(395 - 175)/4$ plus $(881 - 860)/6 = 58.5$ kg U-233/year from the core of a small reactor. Similarly, comparing Case 6 with Case 4 of the reference document yields a productivity of 163 kg U-233/year from the core of a K Reactor. These values were rounded to 60 kg/year and 160 kg/year, respectively.

In the reference document the above productivities were obtained by assuming constant reactor power, higher uranium tube power to compensate for the non-heat producing thoria tubes, and consequent operating efficiencies of only 68.4 and 76.7% in small and K reactors, respectively. The same result is obtained if it is assumed that uranium tube powers are held constant, reactor power is reduced to about 83%, and reactor operating efficiencies of 82% and 92% are encountered in the small and K reactors, respectively. In the rush of replying rapidly to the request for answers to the Group V Study I assumed for purposes of calculation that uranium tube powers were held constant, reactor power was reduced in proportion to the reduced number of heat producing tubes, and reactor operating efficiency was 83%, equivalent to operating 300 days per year.

One E-metal cycle in the core of a small reactor at normal tube powers is 85 operating days; at 83% efficiency this corresponds to about 3-1/2 months of calendar time. During this cycle the reactor produces $(85/300)(60) = 17$ kg U-233. The ThO_2 consumption is $17/0.930 = 18.5$ tons, of which 9.25 tons is in the core at any one time. E-metal inventory is $5.9 \times 17 = 100$ tons. Natural uranium not required is $1.7 \times 100 \text{ tons}/3.5 \text{ months} = 48 \text{ tons/month}$.

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One E-metal cycle in the core of a K Reactor at normal tube powers is 77 operating days; at 83% efficiency this corresponds to about 3 calendar months. During this cycle the reactor produces $(77/300)(160) = 41$ kg U-233. The ThO_2 consumption is $41/0.925 = 45$ tons, of which 22.5 is in the core at any one time. E-metal inventory is $5.9 \times 41 = 242$ tons. Natural uranium not required is $1.5 \times 242/3 = 121$ tons/month.

It is well to verify the above results by an independent calculation. The core of a small reactor contains about 1040 tubes inside the flattening ring, and $1/5.8$ of the tubes, or 180 tubes will contain thoria which at 75% of theoretical density (19.4 tubes/ton) corresponds to 9.25 tons of ThO_2 . Similarly, the core of a K Reactor contains about 2000 tubes inside the flattening ring, and $1/6.8$ of the tubes, or 294 tubes, will contain thoria which at 85% of theoretical density (13.1 tubes/ton) corresponds to 22.5 tons of ThO_2 .

IV. SPECIFIC ASSUMPTIONS RELATED TO SCHEDULES

Fuels Section learned from National Lead that they could start denitrating thorium nitrate at a rate of 60 tons/month after three months lead time. It was assumed that authorization would be received on July 1, 1964, that denitration would start at Fernald on October 1, that enough thoria would be received at Hanford to permit canning to commence on November 1 at a rate of 40 tons per month, and that 30 tons of canned thoria would be ready for reactor loading by December 1.

It is planned to start loading thoria into the core of the small reactors as rapidly as thoria is available. The last 3-1/2 months of operation of H Reactor and the last 7 months of operation of F Reactor will be with a thoria loading. Only half of the core of B Reactor will be loaded with thoria since the other half will contain depleted uranium under a different program. After sufficient canned thoria has accumulated to maintain the operation of the small reactors a thoria loading will then be placed in one of the K Reactors.

Production of a nominal 200 kgs of U-233 will require the equivalent of two E-metal cycles in the core of one K Reactor and two E-metal cycles in the cores of four small reactors -- representing the production of $2(41 + 4 \times 17) = 218$ kg. In practice, we will use two E-metal cycles in half of B Reactor and use one E-metal cycle in the full core of H Reactor.

Production of a nominal 100 kgs of U-233 will require using only one of the two E-metal cycles shown above, plus the full cycle in H Reactor -- representing the production of $(41 + 4.5 \times 17) = 117.5$ kg.

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V. CHEMICAL SEPARATIONS

After two irradiations during one cycle of E-metal in the core of a small reactor, the undecayed Pa-233 is 34.6%. After four irradiations during two cycles of E-metal in the core of a small reactor, the undecayed Pa-233 is 18.5%.

The corresponding values for Pa-233 from the core of a K Reactor are 39.0% and 21.4%, respectively.

For the 200 kg case:

By July 15, B and C will have produced	51	kg with 18.5% Pa =	9.43 kg Pa
D and F will have produced	68	kg with 12.6% Pa =	8.56 kg Pa
H will have produced	17	kg with 5.0% Pa =	0.85 kg Pa
K will have produced	82	kg with 14.6% Pa =	11.92 kg Pa
	<u>218</u>	<u>kg</u> <u>14.1% Pa</u>	<u>30.8 kg Pa</u>

Start processing on October 1, 1965; Pa will then be 4.6 kg, or 2.1%.

For the 100 kg case:

By May 1, B and C will have produced	25.5	kg with 16.0% Pa =	4.1 kg Pa
D and F will have produced	34	kg with 10.9% Pa =	3.7 kg Pa
H will have produced	17	kg with 34.6% Pa =	5.9 kg Pa
K will have produced	41	kg with 18.0% Pa =	7.4 kg Pa
	<u>117.5</u>	<u>kg</u> <u>18.0% Pa</u>	<u>21.1 kg Pa</u>

Start processing on July 1, 1965; Pa will then be 4.55 kg, or 3.9%.

W. W. Woods

Consulting Engineer
Research and Engineering

WK Woods:jm

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TABLE I
WORK SHEET FOR THORIA LOADINGS

	<u>1/2 B + C</u>	<u>D + F</u>	<u>H</u>	<u>K</u>
December 1		18.5		
7				
15	14			
22				
January 1				22.5
7				
15			9.25	
22		18.5		
February 1				
7	14			
15				22.5
22				
March 1				
7			9.25	
15		*18.5		
22				
April 1	*14			*22.5
7				
15				
22				
May 1			* --	
7		18.5		
15				22.5
22	13.75			
June 1				
7				
15				
22				
July 1		* --		* --
7				
15	* --			

* Represents discharge of E-metal and thoria.

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TABLE II

THORIA LOADINGS

		<u>Canned Tonnage</u>	<u>Loaded Tonnage</u>	<u>Discharged Tonnage</u>
December	1	30	18.5	
	7	40	18.5	
	15	50	32.5	
	22	60	32.5	
January	1	70	55	
	7	80	55	
	15	90	64.25	
	22	100	82.75	18.5
February	1	110	82.75	18.5
	7	120	96.5	32.25
	15	*130	119	54.75
	22	140	119	54.75
March	1	150	119	54.75
	7	160	**128.25	64
	15	170	146.5	82.5
	22	180	146.5	82.5
April	1	190	183	119
	7	200	183	119
	15	210	183	119
	22	220	183	119
May	1	230	183	***128.25
	7	238	201.5	146.75
	15		224	169.25
	22		238	183
June	1			183
	7			183
	15			183
	22			183
July	1			224
	7			224
	15			238

Note: Above numbers are for 200 kg case. For 100 kg case change as follows:

- * Change ~~July~~ 15 number to 128 and terminate the column.
- ** Leave March 7 number unchanged, and terminate the column.
- *** Leave May 1 number unchanged, and terminate the column.

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TABLE III
E-METAL LOADINGS

	<u>1/2 B plus C</u>	<u>D plus F</u>	<u>H</u>	<u>K</u>	<u>Cumulative</u>
December 1		200			200
15	150				350
January 1				242	592
15			100		692*
February 1					692
15					692
March 1					692
15		200			892
April 1	150			242	1284

* For nominal 100 kg of U-233, terminate E-metal loadings after 692 tons by January 15.

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TABLE IV
REDUCTIONS IN LOADING OF NATURAL URANIUM, TONS

	<u>1/2 B plus C</u>	<u>D plus F</u>	<u>H</u>	<u>K</u>	<u>Cumulative</u>
December 1					
15		48			48
January 1	36	48			132
15	36	48		60.5	276
February 1	36	48	24	60.5	445
15	36	48	24	60.5	614
March 1	36	48	24	60.5	782
15	36	*48	24	60.5	950
April 1	*36	48	24	*60.5	1119
15	36	48	24	60.5	1288
May 1	36	48	*24	60.5	1456
15	36	48		60.5	1600
June 1	36	48		60.5	1745
15	36	48		60.5	1890
July 1	36	48		60.5	2034
15	36				**2070

* For nominal 100 kg of U-233, reduction in natural uranium would terminate at these values on these dates.

** Value of 2070 is slightly low (vs. 2085) because of rounding.

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