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PERFORMANCE OF THORIUM FUELED FAST BREEDERS

D. R. Marr, D. A. Cantley, J. C. Chandler,
D. C. McCurry, and D. R. Haffner

Hanford Engineering Development Laboratory
Richland, Washington 99352

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Three studies were made of the performance characteristics of thorium-containing reactors. The first of these compared two small breeder designs, one using thorium oxide, the other using thorium metal, both with ^{233}U enrichment. The second compared a plutonium-uranium oxide 1200 MWe design to a uranium-thorium 1200 MWe design. The third compared the performances of thorium metal and thorium oxide radial blankets for three large breeders using uranium or thorium oxide cores and axial blankets.

In the small breeder study, the same heterogeneous core layout was used for both designs. The subassembly used the FTR reference duct, but fuel pins were redesigned to take advantage of improved material properties.

The thorium oxide design was helium bonded and used a 0.275 inch diameter pin in a 169 pin cluster. The metal design was sodium bonded, and used a 0.382 inch diameter pin in a 91 pin cluster. The smear density of the oxide pin was set at 90% TD on the assumption that thorium oxide fuel pins would perform as well as Pu/U mixed oxide pins. The metal pellet radius was sized to accommodate the expected swelling and preclude fuel-cladding mechanical interaction. The swelling rate was calculated as a function of temperature up to 30% $\Delta V/V$; beyond that, the minimum theoretical swelling rate was used. Swelling was assumed to be isotropic.

Breeding performance of the two designs was calculated using the two-dimensional diffusion theory code 2DB[1] in R-Z geometry with the internal blankets modeled as annular rings. The uranium was assumed to be pure ^{233}U. Axial growth of the fuel was not modeled. A cartridge core reload was assumed and the necessary enrichment increase due to ^{233}Pa holdup was included. Performance characteristics are shown in Table I. The metal design shows a slightly better breeding performance than the oxide design, but also shows a higher heavy metal processing requirement. This result, however, is quite sensitive to the swelling rate used for the fuel pin design. The swelling data for thorium metal fuel is quite meager and therefore subject to large uncertainties. A rate larger than that used would have resulted in a design with a lower fuel volume fraction and poorer breeding. Both designs showed a negative reactivity effect due to voiding the flowing sodium in the active core. Both are negative at about three dollars.

In the 1200 MWe study, the comparison is between a large plant using the 217 pin FTR-like assembly fueled with mixed plutonium-uranium oxide and the same plant design using the thorium metal assembly described for the small breeder study. The FTR-like assembly has a total of 28 inches of axial blanket replacing the axial reflectors, whereas the thorium design has 35 inches. Subassembly pitch is 4.76 inches for the thorium design, 4.78 inches for the FTR assembly design. A summary of the designs and the performance characteristics is given in Table II. The breeding performance of the thorium design is seen to be considerably lower than that of the plutonium design, with a doubling time of 83 years compared to 37 years for the plutonium system. The sodium void effect is greatly improved, being minus two dollars for the thorium design versus a positive four dollars for the plutonium fueled design.

In the final study, the effect of replacing a thorium oxide radial blanket with a design using thorium metal was investigated. This effect was calculated for three fast breeders, a $(^{233}U,Th)O_2$ core with ThO_2 axial blanket, a $(^{233}U,^{238}U)O_2$ core with ThO_2 axial blanket, and a $(^{233}U,^{238}U)O_2$ core with UO_2 axial blanket. For all three reactors, the core layout, subassembly design, and fuel pin design were identical and were typical of a good breeding plutonium-uranium design.

The relative performance of the three reactors is shown in Table III. The results show the overall breeding performance to be little affected by choice of radial blanket design.

In summary, thorium metal and thorium oxide designs exhibit comparable breeding. The slight advantage seen for the metal design is based on meager thorium metal swelling data and may change as improved data become available. Uranium-thorium cores provide inferior breeding performance when compared to plutonium-cores but they exhibit greatly improved sodium void effect--voiding reduces reactivity.

Reference

1. W. W. Little, Jr. and R. W. Hardie, "2DB Users' Manual--Revision 1," BNWL-831, Rev. 1, August 1969.

Table I

Comparison of Small Breeder Designs

	Metal	Oxide
Fuel Assembly Design		
Pins/SA	91	169
Fuel Rod O.D. (in)	0.382	0.275
Cladding Wall (mils)	15.0	15.5
Pellet O.D. (in)	0.314	0.2365
Radial Blanket Assembly Design		
Pins/SA	37	37
Pin O.D. (in)	0.647	0.647
Cladding Wall (mils)	15	15
Pellet O.D. (in)	0.583	0.610
Performance Characteristics		
Peak Heat Rate (kW/ft)	31.6	16.5
Residence Time (yrs)	2	2
Average Discharge Exposure (MWD/kg)	60	76
Peak Fluence (E>0.1 MeV)	1.56×10^{23}	1.23×10^{23}
Fuel Enrichment (U/U+Th) (wt%)	23.2	25.3
Core Enrichment (U/U+Th) (wt%)	14.7	15.9
Core Conversion Ratio	0.61	0.63
Breeding Ratio	1.14	1.10
Doubling Time (yrs)	95	140
Sodium Void ($)	-3	-3
Fuel Pins/yr	7098	13182
Kgs Heavy Metal/yr	13098	10323

Table II

Comparison of 1200 MWe Designs

	Thorium Metal	Pu-U Oxide
Fuel Assembly Design		
Pins/SA	91	217
Fuel Rod O.D. (in)	0.382	0.230
Cladding Wall (mils)	15	15
Pellet O.D. (in)	0.3140	0.1935
Radial Blanket Assembly Design		
Pins/SA	37	61
Pin O.D. (in)	0.647	0.506
Cladding Wall (mils)	15	15
Pellet O.D. (in)	0.583	0.469
Performance Characteristics		
Peak Heat Rate (kw/Δt)	27.5	10.8
Residence Time (yrs)	2	2
Average Discharge Exposure (MWD/kg)	51	69
Peak Fluence (E>0.1 MeV)	$2.69x10^{23}$	$1.87x10^{23}$
Fuel Enrichment (%)	11.8/14.7	18.1/21.8
Core Conversion Ratio	0.70	0.74
Breeding Ratio	1.12	1.17
Doubling Time (yrs)	83	36.5
Sodium Void ($)	-2.1	+4.28
Fuel Pins/yr (core only)	29939	73563
Kgs Heavy Metal/yr (core & blkts)	39105	27849

Table III

Comparison of Thorium Blanket Designs

Radial Blanket Assembly Design

Blanket Material	ThO_2	Th
Theoretical Density (g/cc)	10.0	11.7
Pins/SA	127	61
Pin O.D. (in)	0.4657	0.667
Cladding Wall (mils)	15	15
Pellet O.D. (in)	0.4287	0.6067

Fuel Assembly Design

Fuel Material	$(U3,U8)O_2$	$(U3,U8)O_2$	$(U3,Th)O_2$
Theoretical Density (g/cc)	11.0	11.0	10.1
Pins/SA	271	271	271
Axial Blanket Material	UO_2	ThO_2	ThO_2
Theoretical Density (g/cc)	11.0	10.0	10.0
Fuel Rod O.D. (in)	0.286	0.286	0.286
Cladding Wall (mils)	12	12	12
Smear Density	88	88	88

Performance Characteristics

	U3-U8/U8/Th		U3-U8/Th/Th		U3-Th/Th/Th	
	Oxide Blanket	Metal Blanket	Oxide Blanket	Metal Blanket	Oxide Blanket	Metal Blanket
k_{eff} - BEC	1.053	1.052	1.052	1.053	1.035	1.038
- EEC	1.001	1.000	1.000	1.000	0.999	1.000
Breeding Ratio-MEC	1.187	1.190	1.180	1.180	1.063	1.058
Conversion Ratio-MEC	0.895	0.893	0.890	0.885	0.789	0.781
Fissile Load-kg	3644	3662	3666	3696	4142	4194
Enrichment (U/U+Th)-w/o						
Core 1	8.71	8.75	8.76	8.83	10.86	10.99
Core 2	11.32	11.36	11.39	11.47	14.17	14.35
Doubling Time - yrs	22.8	22.5	24.8	24.8	185	222