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OPTIMUM PIN DIAMETER FOR LMFBR ADVANCED FUELS

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DISCLAIMER

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The energy crisis has re-emphasized the importance of achieving short doubling times in an LMFBR so that our uranium resource is fully utilized.[1,2] Carbide fuel will produce shorter doubling times than oxide fuel.[1,2] Therefore, previous carbide fueled core design studies[3] were recently extended[4] with primary emphasis on minimizing doubling time and less emphasis on fuel cycle cost.

Of the several design parameters that affect doubling time, fuel pin diameter is the most important. Another important parameter is the tightness of the pin packing or fuel pin pitch to diameter ratio (P/D). A small pin diameter gives a low fissile inventory which reduces the doubling time. On the other hand, large pin diameters lead to large fuel volume fractions which maximize the breeding ratio and thereby lower the doubling time. The pin diameter which yields the lowest doubling time is that which achieves the best balance between breeding and inventory. Tight pin packing also tends to maximize the fuel volume fraction, thus maximizing breeding ratio and minimizing doubling time. However, tight pin packing increases coolant velocity and pressure drop and thus increases the amount of steel in the core. Tightly packed cores with a range of fuel pin diameters were therefore investigated in this study. The study was primarily concerned with determining whether there is an incentive for developing high velocity, low P/D designs utilizing relatively small diameter fuel pins.

Core designs were based on thermal-hydraulic and reactor physics calculations to ensure that each configuration incorporates consistent and realistic engineering limits. Proper allowances for fuel, clad and subassembly shroud swelling were made. The fuel enrichments were chosen to account for reactivity changes due to burnup and provide proper power distributions between the two core enrichment zones.

Two-dimensional multigroup diffusion theory was used for the cylindrical geometry reactor physics calculations.

Each core configuration has a nominal power of 1000 MWe. The active fuel height is 3 feet,(3) the axial blanket thickness is 1.5 feet, and the radial blanket has three rows of subassemblies. Each reactor has the same number of subassemblies with 91 pins per driver subassembly. Hyperstoichiometric sodium-bonded carbide fuel at 98% of theoretical density with a peak linear pin power of 30 kw/ft was used in each case. A mixed mean coolant temperature rise of 300°F was used. At constant pin diameter, variation in fuel pin pitch was achieved by varying coolant velocity.

All cases studied are fluence limited. The entire study was repeated for two fluence limits; the first based on near term technology (stainless steel, $\Delta V/V = 10\%$ at 1.8×10^{23} nvt, $E > 0.1$ Mev), the second based on advanced technology using a high nickel alloy which would experience no more than 5% volumetric swelling at a fluence of 3.6×10^{23} nvt. The range of pin diameters and coolant velocities considered are given in Table 1.

The results of the study are shown in Table 1. A minimum in the doubling time occurs at a pin diameter in the range 0.37" to 0.40" for both the near term and advanced technology assumptions. The minimum fuel cycle cost occurs in the same range of pin diameters. Because higher burnups are achievable with advanced technology, the fuel cycle cost is significantly lower than for near term cores; however, the doubling time is only 0.7 years lower for cores designed with advanced clad and structure. This is due to the larger fission product inventory and lower fuel smear density occurring in the higher burnup cores.

The influence of coolant velocity variations on doubling time is much weaker than that of the pin diameter. For larger pins, increased coolant velocity has little effect on doubling time or fuel cycle cost. For the smaller pins, increasing the coolant velocity reduces the doubling time quite significantly; however, at no velocity does the smaller pin have a lower doubling time than the larger pin.

For carbide cores designed to operate at limits established by clad performance, the optimum fuel pin diameter lies in the range from 0.37" to 0.40". Reducing the pin spacing by increasing the coolant velocity doesn't reduce the optimum pin diameter significantly. Introduction of an advanced cladding more resistant to neutron damage also has little effect on the optimum pin diameter. Sodium-bonded carbide fuel has an optimum pin diameter somewhat larger than LMFBR oxide fuel.

References

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4. J. A. Vitti, Ed., "Preliminary Assessment of Proof Testing LMFBR Carbide Fueled Subassemblies in FTR Driver Positions," CEND-370, to be published under AEC Contract AT(11-1)-2426.

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Table 1

Carbide Subassembly Optimization Study Results

Near Term Cladding and Shroud Material: Peak Fluence 1.8 x 10^{23} nvt, Peak Swelling 10% Δv/v, Strength Limit 15,500 psi

Pin O.D. (in.)	Velocity (ft/sec)	Pin P/D	ΔP (psia)	Fuel Volume Fraction	Average Enrichment (wt %)	Seed Fissile Inventory (kg)	Peak Burnup (Mwd/kg_{HM})	Breeding Ratio	Fuel Cycle Cost* (mills/kwhr)	Compound Doubling Time** (yr)
0.295	26	1.32	57.7	0.265	13.13	1881	91.1	1.29	1.48	14.4
0.370	26	1.19	62.5	0.361	10.34	2526	72.5	1.48	1.30	10.9
0.456	26	1.11	71.0	0.450	9.02	3600	64.9	1.60	1.35	11.7
0.370	20	1.26	32.1	0.331	10.72	2616	75.3	1.46	1.29	11.7
0.370	35	1.13	137.4	0.381	10.21	2492	71.1	1.48	1.33	11.0

Advanced Cladding and Shroud Material: Peak Fluence 3.6 x 10^{23} nvt, Peak Swelling 10% Δv/v, Strength Limit 40,000 psi

Pin O.D. (in.)	Velocity (ft/sec)	Pin P/D	ΔP (psia)	Fuel Volume Fraction	Average Enrichment (wt %)	Seed Fissile Inventory (kg)	Peak Burnup (Mwd/kg_{HM})	Breeding Ratio	Fuel Cycle Cost* (mills/kwhr)	Compound Doubling Time** (yr)
0.295	26	1.32	58.9	0.260	13.54	1757	185.5	1.20	0.94	17.5
0.370	26	1.19	63.1	0.361	10.37	2354	144.8	1.42	0.80	10.3
0.456	26	1.11	72.0	0.442	9.12	3319	131.0	1.53	0.87	11.4
0.370	35	1.13	136.9	0.390	10.11	2292	140.6	1.43	0.81	9.9
0.295	45	1.17	228.5	0.315	12.33	1600	171.7	1.25	0.94	12.7
0.295	35	1.23	120.3	0.294	12.69	1647	176.4	1.24	0.91	13.4

*Including cost of pumping power

**A definition similar to that of Wycoff and Greebler was used.(5) It includes out-of-pile inventory, fuel processing losses, and ^{241}Pu decay.