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Design and Economic Implications of Heterogeneity in an LMFBR Core*

by

Yuri Orechwa

Argonne National Laboratory
9700 S. Cass Avenue
Argonne, Illinois 60439

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A nuclear fueled power plant depends, vis-a-vis fossil fueled power plants, on its lower fuel cycle cost for achieving an economically competative edge. In the context of nuclear power, it is generally accepted that LMFBRs will have a higher capital cost than LWRs, and thereby the fuel cycle of the LMFBR is expected to make up this differential in capital cost. Traditionally, the continuous reduction in the availability of high grade uranium was expected to increase the fuel cycle cost of the LWR to the extent that the LMFBR becomes economically competative. However, results from the ongoing NURE program appear to indicate that uranium will be available at a grade sufficient to make a rapid increase in its price unlikely for a considerable time. In light of this, much emphasis is currently being placed in LFMBR design on reducing both the capital cost and the fuel cycle cost of an LMFBR to insure its economic competativeness without a rapid increase in the uranium prices.

In this study we focus on the relationship between two core design options, their neutronic consequences, and their effect on fuel cycle cost. The two design options are the selection of pin diameter and the degree of heterogeneity. By the latter we mean the ratio of fertile internal blanket to driver assemblies. In the case of a heterogeneous core, with a low sodium void reactivity worth this ratio is generally about 0.40.[1] However, some advantages of cores with heterogeneity of 0.08 to 0.2 for a fixed pin diameter have been reported.[2] It is well known that many of the heterogeneous core's advantages can be duplicated by a homogeneous core through a proper choice of pin diameter.[3] Thus, to gain a proper perspective as to the merits of a certain level of heterogeneity, the effect of pin diameter must also be taken into account.

To this end a series of mixed oxide fueled core designs have been analyzed, with heterogeneity in the range 0.4 to 0.0, and with fuel pin diameters from 0.275 in. to 0.370 in. The fuel assemblies were designed in each case for a 1000 MWe output and consistent with a 930°F reactor coolant outlet temperature and a 280°F temperature rise across the core. In determining the layout of internal blankets within the driver region particular attention was paid to power peaking over a burn cycle. The neutronic analysis was performed in three dimensional Hex-Z geometry with eight energy groups. The burnup calculations, for eqilibrium conditions, were performed with the code REBUS-3[4] and the reactivity coefficients were calculated with VARI-3D[5] using first order perturbation theory. Two expedients have been assumed which reduce fuel cycle cost independent of heterogeneity or pin diameter; these are a three year fuel residence time and the replacement of radial blanket assemblies by reflector assemblies. The former increases the uncertainty with respect to fuel performance, while the latter results in reduced breeding performance.

In Table I are shown representative neutronic parameters for the cores as a function of heterogeneity and pin diameter. It is clear that for a 0.275 in. pin diameter and heterogneity of ~40% - which are the parameters for current U.S. designs - lower heterognetiy would result in a poorer performance with respect to all the listed parameters except for fissile loading. However, if we include pin diameter variation, these advantages begin to reverse. The one parameter which does not reverse, and is one of the main rationals for higher heterogeneity, namely the driver sodium void reactivity, increases linearly with a reduction in the degree of heterogeneity from 40% to 0% by a factor 1.5. The effect of pin diameter is small.[6]

Better fuel cycle economics can be achieved in a reactor by extending the residence time of the fuel. An important core design parameter which limits the fuel residence time is the fast fluence; which varies with both the degree of heterogeneity and fuel pin diameter. In Fig. 1 is shown the relative fuel cycle expense for different cores with the residence time normalized to a fluence of 2.2×10^{23} nvt (i.e. that associated with a 40% heterogeneity and a 0.275 in. pin diameter). Clearly considerable savings in fuel cycle expense can be achieved by either increasing the degree of heterogeneity or increasing the fuel pin diameter. or both. However, the savings that result from these design options are tempered by their effect on the primary system. For example, the larger pin diameter and a greater degree of heterogeneity will, in general, lead to a larger vessel diameter and thereby increase capital cost. In spite of these considerations, however, the savings in fuel cycle expense as indicated in Fig. 1 appear to be sufficient to outweigh these drawbacks.

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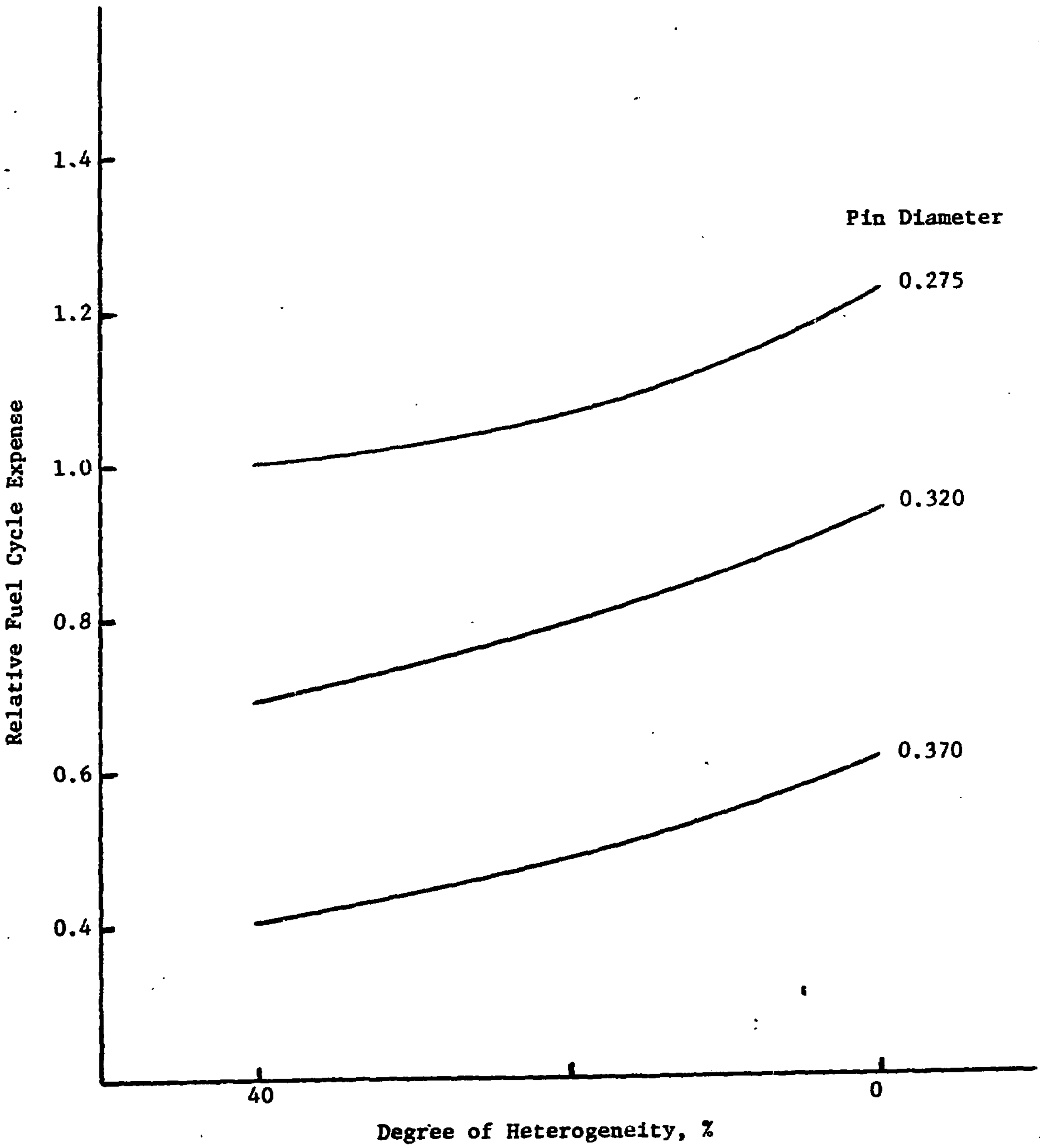

Fig. 1. Relative Fuel Cycle Expense Normalized to a 2.2×10^{23} nvt Fast Fluence

TABLE I. Neutronic Parameters as a Function of Degree of Heter
and Pin Diameter, Equilibrium Cycle Conditions

Heterogeneity, %		40			17	
Pin Diameter, in.	0.275	0.320	0.370	0.275	0.320	0.37
Equilibrium Cycle Pu Loading, kg	1622	1918	2320	1488	1751	215
Δk	-0.012	-0.003	-0.002	-0.015	-0.002	+0.0
Peak Burnup, MWd/T	125,000	92,000	72,500	125,000	90,500	68,5
Peak Fast Fluence, nvt	2.2×10^{23}	1.8×10^{23}	1.54×10^{23}	2.4×10^{23}	1.98×10^{23}	$1.60 \times$
Reactor Breeding Ratio	1.127	1.221	1.292	1.099	1.215	1.29

Parameters as a Function of Degree of Heterogeneity
iameter, Equilibrium Cycle Conditions

		17			0	
70	0.275	0.320	0.370	0.275	0.320	0.370
20	1488	1751	2153	1286	1479	1821
002	−0.015	−0.002	+0.004	−0.024	−0.001	+0.007
500	125,000	90,500	68,500	132,000	98,000	72,000
$\times 10^{23}$	2.4×10^{23}	1.98×10^{23}	1.60×10^{23}	3.10×10^{23}	2.31×10^{23}	1.79×10^{23}
92	1.099	1.215	1.295	1.064	1.208	1.302