EVALUATING THE EFFICACY OF A MINOR ACTINIDE BURNER

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ABSTRACT

The efficacy of a minor actinide burner can be evaluated by comparing safety and economic parameters to the support ratio. Minor actinide mass produced per unit time in this number of Light Water Reactors (LWRs) can be burned during the same time period in one burner system. The larger the support ratio for a given set of safety and economic parameters, the better. To illustrate this concept, the support ratio for selected Liquid Metal Reactor (LMR) burner core designs was compared with corresponding coolant void wortbs, a fundamental safety concern following the Chernobyl accident. Results can be used to evaluate the cost in reduced burning of minor actinides caused by LMR sodium void reduction efforts or to compare with other minor actinide burner systems.

I. INTRODUCTION

Numerous physics studies have shown that actinide waste discharged from Light Water Reactors (LWRs) could be burned in Liquid Metal Reactors (LMRs) as well as other systems. Relationships between safety and economic parameters and minor actinide burn rates are usually established. However, it is difficult to determine from these trade-off studies how effective one burner system is relative to others. In fact, witbin any one design, optimizing these relationships is a multi-dimensional problem. It would seem logical, within the systems design approach to this problem, to relate all parameters to one that is an indicator of how good the system is. That measure of quality should be how much of the high-level waste from LWRS the burner system can eliminate.

Therefore, safety and economic parameters should be related to a parameter called the support ratio. Minor actinide mass produced per unit time from this number of LWR plants can be burned during the same period of time in one burner system. As a measure of efficacy, the larger the support ratio for a given set of safety and economic parameters, the better the burner system. Different systems could use the same relationships and quantitative comparisons could be drawn.

Unfortunately, good safety, economics, and waste burning do not generally co-exist. As a result, many parameters are required to evaluate a system. However, random selection of parametric relationships may lead to considerable time studying concepts that will not work. Following the Chernobyl accident, one disqualifying parameter is a significant positive coolant void reactivity coefficient. Therefore, for any system where coolant void can be a problem, this feedback should be examined early in the design.

To illustrate this concept, sodium void worth and minor actinide burn rate were analyzed for an LMR and intercompared using the support ratio definition, above. Minor actinide loading and core height were varied as a means to establish relationships between void worth and minor actinide burn rate for study purposes, Obviously, many other parameters are involved in a burner design, but they are beyond the scope of this paper.

II. CORE LOADING

This study of the sodium void reactivity worth versus support ratio was performed for a selection of core designs based on one 471 MW module of an LMR similar to the one described in Reference 1. Multiple modules would be identical and add together to form a plant equivalent in power to an LWR. The LMR fuel assemblies contained a combination of plutonium and uranium with the fuel pin and assembly dimensions of Reference 1. A nitride fuel matrix was selected for performance reasons discussed later. However, with slight adjustments, the results and conclusions drawn for nitride fuel would be applicable for other fuel types. Certainly the parametric concept illustrated here would be applicable for all fuel types.

Plutonium enrichment in the fuel assemblies was varied to handle the particular minor actinide target load. Minor actinides were loaded into separate assemblies for reprocessing ease. These target assemblies had the same pin and assembly dimensions as the fuel assemblies. Relative abundances of neptunium, americium, and curium changed during the process of transmutation. Table 1 shows their mass fractions as discharged from LWRs[2] and

Table 1. Minor Actinide Isotopics.

Nuclide	LWR Discharge Mass Fraction	LMR Recycle Mass Fraction
Np-237	0.41780	0.34694
Pu-238		0.13886
Pu-239		0.00807
Pu-240		0.00637
Pu-241		0.00016
Pu-242		0.01866
Am-241	0.47762	0.34951
Am-242m	0.00063	0.02268
Am-243	0.08603	0.06597
Cm-242		0.00655
Cm-243	0.00032	0.00049
Cm-244	0.01671	0.03200
Cm-245	0.00089	0.00374

the mass fractions after several passes through an LMR where fission products are replaced with LWR discharge material representing recycling of the minor actinides[3]. Minor quantities of uranium and other isotopes of neptunium, plutonium, americium, and curium that build-in during the irradiation do not significantly contribute to the problem and were thus ignored. No higher actinide mass isotopes are included because analyses show virtually no buildup of higher actinides in this neutron spectrum. This work included sodium void worth and support ratio calculations using minor actinide isotopics representing LWR discharge and LMR recycle waste streams.

Both homogeneous and heterogeneous LMR reactors were studied. The heterogeneous core consisted of fuel, internal blankets, radial blankets, and minor act inide assemblies in various core arrangements. Fuel was located as shown in Figure 1, but the number of minor actinide target assemblies was varied. The homogeneous core consisted of internal fuel occupying the fuel and internal blanket locations of Figure 1, surrounded by either minor actinide assemblies and/or blanket assemblies.

HI. ANALYSIS METHODS

Sodium void worths were computed with three-dimensional diffusion theory code 3DB[4]. Neutron cross sections from ENDF/B-V[5] were prepared using the shielding factor method' for both sodium voided and sodium flooded cases. Sodium was voided only from the fuel, blanket, and minor actinide burner assemblies. Resultant reactivity changes were computed using the k_{eff}-difference method. Void worths were computed for cores containing LWR discharge minor actinide densities and for cores containing minor actinides recycled through an LMR.

The support ratio was computed from the comparison of the mass of minor actinides burned in each case to the mass generated in equivalent sized LWRs. The capacity factor was assumed to be the same between an LMR burner and the LWRs. Minor actinides produced by the burner system were included in what must be burned.

IV. WORKSCOPE

Design of a burner system requires many trade-off studies. The main objective of this work was to suggest a systems-related concept of comparing trade-off parameters against the support ratio. For illustration, the sodium void worth and the minor actinide mass change with burnup were studied and reported here.

Reduction of the sodium void in an LMR system may involve both geometry changes to affect neutron leakage, as we] l as, material changes to alter the neutron spectrum. Because time allotted to this study was limited, only leakage effects were included and onl y the height-to-diameter ratio was altered to achieve an effect. Analyses were performed for a tall 135-cm-high core as well as a shorter 76-cm-high alternative core that still exhibited satisfactory linear heat rates, at least for the nitride core studied.

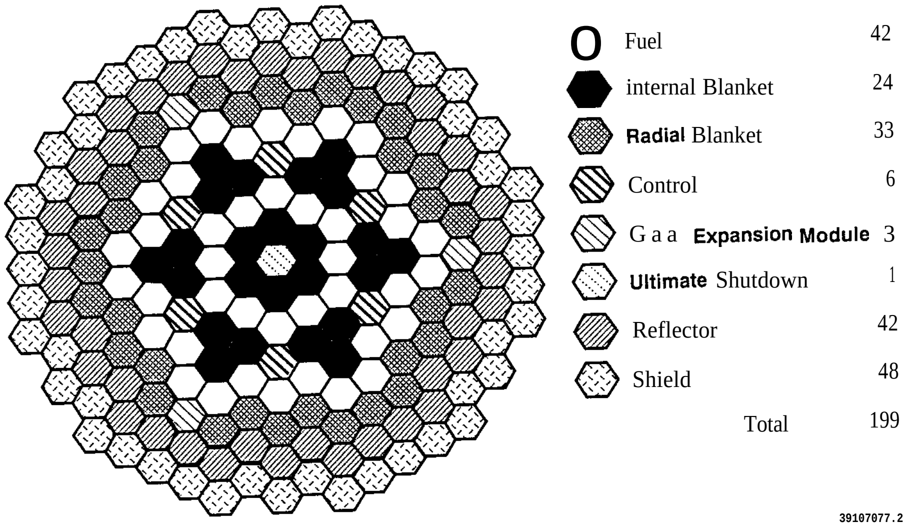

Fig. 1. Advanced Liquid Metal Reactor Core

V. RESULTS

Heterogeneous core arrangements of plutonium/uranium fuel, blankets, and minor actinide target assemblies were used to study how the sodium void reactivity and support ratio varied with actinide target assemblies scattered throughout the core. Case 1 was the reference LMR core with 42 fuel, 24 internal blanket, and 33 radial blanket assemblies as shown in Figure 1. In Case 2, the 42 fuel assemblies were replaced with minor actinide target assemblies containing LMR recycle-type material of Table 1. For Case 3, 6 internal blankets and 12 radial blankets from the reference core were replaced with minor actinide target assemblies. For Case 4, 18 fuel assemblies from the reference core were replaced with minor actinide assemblies. Figure 2 shows the sodium void worth for each of these cases examining both 76-cm and 135-cm-high variations of these core loadings. Reactivities are reported in units of dollars based upon a delayed neutron fraction (Beta) of 0.0037 representing the reference case. Actually, the quantity and position of minor actinides loaded into the core changes the value of Beta. It is beyond the scope of this work to calculate that value for each loading. The purpose of this work is to show how the concept of support ratio can aid in feasibility studies of burner systems. Also included in Figure 2 are calculations where all the blanket assemblies throughout the core are replaced with minor actinide targets. These results are almost identical to those of the full-core minor actinide for fuel replacement.

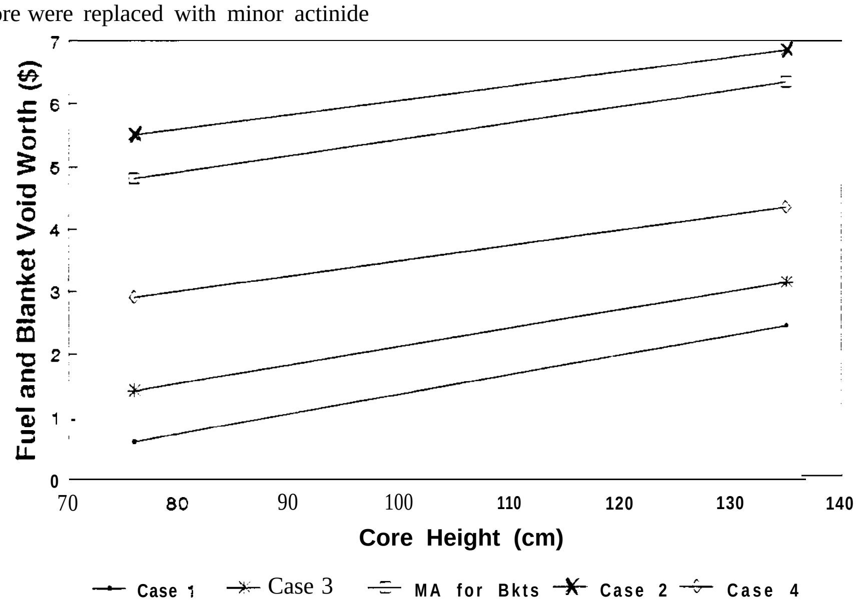

Fig. 2. Sodium Void Worth for Heterogeneous Core.

In an alternative core arrangement, minor actinide assemblies were substituted for radial blankets around the periphery of a homogeneously fueled core without internal blankets or targets. Case 5 is the reference homogeneous case that consisted of 66 driver fuel assemblies surrounded by 33 radial blankets. In Case 6, the 33 blankets were replaced with minor actinide target assemblies containing LMR recycle type material of Table 1. For Case 7, only 18 of the blankets of Case 5 were replaced with minor actinide targets. Case 8 is a repetition of Case 6 except that the target assemblies contained LWR discharge type material of Table 1. Case 9 is a repetition of Case 7 with the LWR discharge type material. Cases 5 through 9 sodium void worth results are found in Figure 3.

Results from Cases 5 through 9 were recast in Figure 4, where the sodium void worth is plotted against the quantity of minor actinides loaded into the core. These data illustrate how the sodium void worth becomes more positive as the minor actinides are burned.

To establish the support ratio, the burnout rates of the minor actinides in each of these cases were computed accounting for only fission of these nuclides. Capture to another minor actinide does not eliminate it from the minor actinide inventory. Table 2 summarizes the results of all nine cases.

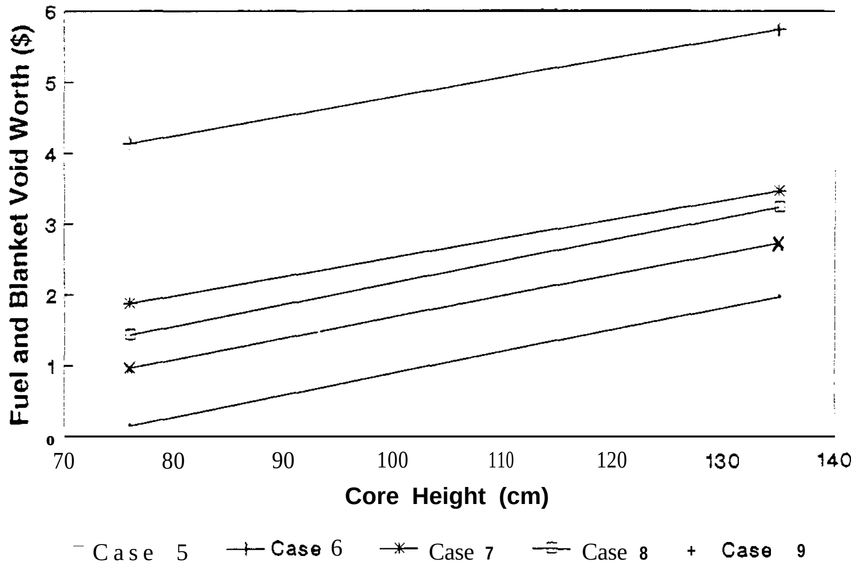

Fig. 3. Sodium Void Worth for Homogeneous Core.

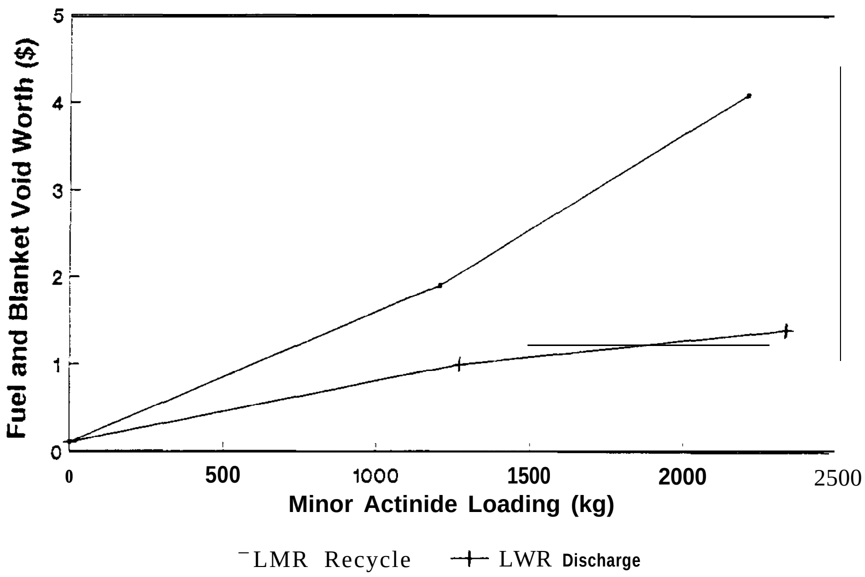

Fig. 4. Minor Actinide Loading Effect on NA Void.

Table 2. Sodium Void Worth and Support Ratios for Selected LMR Core Arrangements.

Case	No. of Fuel Assemblies	No. of Internal Blanket Assemblies	No. of Internal Minor Actinide Assemblies	No. of Radial Blanket Assemblies	No. of Radial Minor Actinide Assemblies	support Ratio[c]	Sodium Void worth ($)[d]	
							53" Core	30" Core
1	42	24	0	33	0	—	2.4	0.6
2	0	24	42	33	0	24.3	6.8	5.5
3	42	18	6	21	12	13.3	3.1	1.4
4	24	24	18	33	0	10,6	4.3	2.9
5	66	0	0	33	0	—	2.0	0.1
6	66	0	0	0	33[a]	17.7	5.7	4.1
7	66	0	0	15	18[a]	5.9	3.5	1.9
8	66	0	0	0	33[b]	5.1	3.2	1.4
9	66	0	0	15	18[b]	2.2	2.7	1.0

(a) LMR Recycled Minor Actinide Target Composition
t.%) LWR Discharge Minor Actinide Target Composition
(c) Minor actinide mass produced per unit time from this number of LWR planta, plus the burner system itself, can be burned during the same time by one burner system.
(d) The effective delayed neutron fraction was assumed to equal 0.0037; calculation of Beta for each minor actinide loading was beyond the scope of this work.

VI. CONCLUSIONS

From the summary of results in Table 2, the following conclusions can be drawn from this study of burning actinides in conventional LMR systems.

1. With the proper selection of location for minor actinides, an LMR burner with a support ratio of 10 and sodium void coefficient no larger than for present conventional LMR designs is feasible.
2. The core would consist of approximately 23% minor actinides.
3. Minor actinides must be recycled through the LMR, otherwise the support ratio drops by a factor of 3.
4. Generally, the greater the transmutation rate, the higher the sodium void worth.
5. Reducing the height-to-diameter ratio of the core reduced the positive void coefficient in every case.
6. To obtain near-zero sodium void reactivity coefficient, a void worth reduction scheme more dramatic than the reduction in core height shown here is required.

VII. REFERENCES

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