ASSESSMENT OF THE TELEDIAL GAS-COOLED TRANSMUTER CONCEPT

by

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The application of four gas-turbine, modular helium cooled reactors and an accelerator unit (GT/AD-MHR)[1] has been proposed for burning transuranics recycled from LWR waste. The recycled LWR discharged transuranics encapsulated in TRISO coated particles are first loaded into the outer thermal spectrum zone of the GT/AD-MHR for burning in the critical mode for about three years. Previously burned fuel is in a central fast zone. In the fourth year, the same unit is configured as an accelerator-driven system, containing a centrally located spallation target. The three-year, thermal-zone burned fuel and the inner fast-zone fuel from the critical mode operation are used in this subcritical cycle, and remain in their respective zones. At the end of this one-year subcritical irradiation, the outer thermal-zone fuel is reconstituted and used as fast-zone fuel in another critical mode operation. As the fuel in the fast-zone has reached its end of life it is discharged, with very low transuranics content. The critical mode operation is staggered, and each GT/AD-MGR unit undergoes the subcritical burn in one out of four year. The physics performance of the GT/AD-MHR has been evaluated using independent deterministic and Monte Carlo codes and the results of the study are presented in the current paper. A companion paper discussing the verification of the codes is also presented at this meeting.[2]

Single-batch and three-batch fuel loading schemes for the GT/AD-MHR have been evaluated using the REBUS-3/DIF3D[3,4] fuel cycle code, to determine the feasibility of achieving very high burnup without exceeding reactivity and power density limits.

The reactor physics of the GT-MHR is complicated by the presence of the low-lying plutonium and Er-167 resonances (0.2-1.1 eV) and by the fact that the neutron spectrum has a low-energy peak about this energy range. This peak can change depending on the core state or material loading. The location of the peak and the direction of the spectral shift greatly affect both the resonance fission and capture rates and dictate the core or element criticality state and the magnitude and sign of reactivity coefficients. For these reasons, 23-energy-group, burnup-dependent microscopic cross sections are employed in the REBUS-3/DIF3D model used for evaluating the system. These cross sections were generated with the DRAGON code,[5] using ENDF/B-VI data.

Table 1 contains the summary of core performance parameters for the three-batch and single-batch cases, for an initial heavy metal loading of 1054 kg. Initial Er-167 (burnable poison) loading is specified in the Table. The Er-167 amount used in these calculations is lower than that likely to be used in the final design. Er-167 loading is important because Er-167 is used in the critical operation mode to reduce the initial excess reactivity and additionally to ensure that the isothermal temperature coefficient at the operating temperature range is negative. Additionally, in the results on Table 1, the subcriticality level of the single batch core was realized by adding more burnable poison prior to the start of the accelerator-driven-mode calculation.

Very high consumptions of both Pu-239 and the heavy nuclides were obtained for these cores. The consumption amounts reported are however generally lower than the values previously reported. The higher heavy nuclide consumption for the three-batch core relative to the single-batch core is due to the longer discharge cycle length (see Table 1). The single batch core has a higher initial k-effective in the critical cycle because fresh fuel elements are used. A combination of control rods and burnable poison would be employed to control the excess reactivity in the initial stages of the cycles. The multiplication factor of the accelerator-driven cycle for the three-batch core varies from 0.963 to 0.732, implying a seven-fold increase in the source strength over the cycle, to keep the power level constant. A five-fold increase is indicated for the single-batch core. This is due to the low fissile inventory at the beginning of the subcritical cycle.

The power fractions of the fast and thermal zones are fairly constant during the critical operation cycle in both the single-batch and three-batch cores. The fast-zone accounts for about

3-5% of the total power in both of these cores. The power fraction of the fast–zone increases however with burnup in the accelerator-driven cycle, for both the single-batch and three-batch cores. As the system becomes more subcritical, and as the neutron multiplication in the thermal-zone decreases and results in higher peaking.

The core radial and axial power distributions were investigated for both the critical and accelerator-driven cycles. It was found that the critical operation power distributions are relatively flat and the peak is within acceptable limits. The power peaking is more pronounced in the accelerator-driven cycle than in the critical operation cycle. The highest power densities were observed in the fast-zone of the accelerator-driven cycle, and they increase with irradiation time. Additionally, the axial power profile of the fast-zone peaks significantly at the center, because this is the level that the external source is located. Because the fast zone sees about 3-5% of the total power during the critical operation cycle, the plutonium and heavy-metal consumption rates of the fuel residing in this zone is quite small. Additionally, since the fast zone also sees about 10 to 40% power during its stay in the accelerator-driven cycle, the overall consumption of fuel in this zone limited. The total heavy-metal (implying minor actinides) benefit more from the fast–zone irradiation than Pu-239. This is due to the harder neutron spectrum in this zone. The fast-zone spectrum is however softer than that possible in a fast core transmuter. It is however possible to harden the fast-zone spectrum by either reducing the graphite density in the transition region between the fast and thermal zones or by using an absorber to reduce the neutrons scattering back from the thermal to the fast zone.

Sensitivity studies have indicated design changes that could be used to improve core performance. Lowering the initial heavy metal loading can increase the Pu-239 and heavy-metal consumption rates, for the same power level. A sensitivity study of the initial fuel mass showed that an initial heavy-metal loading of 500 kg is possible. Coupling this reduced mass with a larger fuel particle diameter (in the dispersion fuel matrix) would ensure a critical system. This is because spectral shift and self-shielding effects cause the k-infinite to increase with decrease in initial mass and increase in fuel kernel diameter (for same mass), from the reference design; a higher Er-167 loading would be required to control the excess reactivity. In this event however, the cycle length would decrease.

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Table I: Performance Parameters for Three-Batch and Single-Batch GT/AD-MHR Cores.

Parameter	Core	
	Three-Batch	Single-Batch
Total Fresh Heavy Metal Loading, kg	1054	1054
Total Initial Erbium-167 Loading, kg	0.6186	0.6186
Cycle Length, Effective Full Power Days		
Critical Cycle	270	720
Accelerator-Driven Cycle	270	240
Initial Critical Mode k-effective	1.074	1.137
Initial Accelerator-Driven Cycle Multiplication Factor	0.963	0.963
Final Accelerator-Driven Cycle Multiplication Factor	0.732	0.827
Fast-Zone Discharge Consumption Level		
Pu-239 Consumption, %	97	94
Net Plutonium Consumption, %	71	61
Net Heavy Metal Consumption, %	64	56
Fractional Power Contributed by Fast-Zone		
During Critical Operation, %	3	4
During Accelerator-Driven Operation, %	10-40	10-40