PHYSOR 2004 -The Physics of Fuel Cycles and Advanced Nuclear Systems: Global Developments
Chicago, Illinois, April 25-29, 2004, on CD-ROM, American Nuclear Society, Lagrange Park, IL. (2004)

Low-Conversion Ratio Gas-Cooled Fast Reactors

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The neutronic feasibility and performance of gas-cooled fast burner (GFR) cores designed for low conversion ratio (0.86 to 0.00) have been investigated. Two distinctly different fuel types were evaluated. These are a block-type fuel assembly using dispersion fuel in a low neutron absorbing, neutron moderating SiC matrix and a pin-type fuel assembly using solid solution fuel clad with neutron absorbing Nb-1Zr.

The results of these calculations show several trends with potential safety implications. Very low conversion ratios (CRs) result in large burnup reactivity losses. The delayed neutron fraction and prompt neutron lifetime decrease with conversion ratio. The magnitude of the Doppler reactivity coefficient is reduced at very low conversion ratios and is near zero for the pin fuel. For the block fuel, the Doppler reactivity coefficient has a large negative value for CR=0, which may be a significant safety advantage for this type of fuel. As the conversion ratio decreases, the helium void worth remains roughly constant for the block fuel, but increases significantly for the pin fuel.

The results for the GFR designs compare favorably with those for a sodium-cooled fast reactor (SFR). Parametric studies were performed to evaluate the impact of a number of design choices, which had relatively little effect on the performance of the GFR.

KEYWORDS: Gas-Cooled Fast Reactor, Transmutation

1. Introduction

Gas-cooled fast reactor (GFR) designs are being developed to meet Generation IV goals of sustainability, economics, safety and reliability, proliferation resistance and physical protection as part of an International Nuclear Energy Research Initiative (INERI) project. A fundamental aspect of the project is a high coolant (helium) temperature required for high thermal efficiency and hydrogen production, which puts severe requirements on the materials that may be used in the GFR. Recent activities have focused on transuranic (TRU) self-sufficient designs and a range of fuel types.

In order to manage the surplus transuranic (TRU) inventory in the U.S. LWR spent nuclear fuel stockpile, however, it is desirable to have a low-conversion ratio (burner) reactor. Low conversion ratio implies high TRU enrichment up to 100% for zero conversion ratio systems. This high TRU enrichment also allows for much lower fuel volume fractions. Achieving adequate fuel performance (fuel loading and lifetime) is a significant design challenge because the high operating temperatures limit material choices. The reduced fuel volume fraction of the low conversion ratio system might simplify the design and improve the performance of the high temperature GFR fuel. Two leading TRU self-sufficient concepts for the high temperature (850 °C outlet) GFR were modified and evaluated in this work for use as low conversion ratio

TRU burner designs. These designs utilize a block-type fuel assembly containing dispersion fuel in a low neutron-absorbing and neutron-moderating SiC matrix and a pin-type fuel assembly using solid solution fuel clad with neutron absorbing Nb-1Zr.

For this work, the goal is to evaluate the potential and performance trade-offs for adapting the GFR design concepts to achieve low conversion ratios. In Section 2, the details of the reactor physics models implemented for the fuel cycle and performance calculations are given, while in Section 3 the results for the low conversion ratio GFR designs are discussed. In Section 4, fuel cycle variations are evaluated for a wide range of TRU feed options. The core performance characteristics of the GFR designs are compared to those of a compact sodium-cooled fast burner reactor in Section 5. In Section 6, the conclusions from this work are presented.

2. Computational Models

The ANL suite of fast reactor analysis codes was used to evaluate reactor operating characteristics. Specifically, the MC^2-2, REBUS-3, VARI3D, and DIF3D codes were used. What follows is a brief description of each code.

Full-core, equilibrium-cycle calculations were performed using the REBUS-3 fuel cycle analysis code [1]. An enrichment search was done to determine the TRU enrichment required to achieve an end of equilibrium cycle (EOEC) k_{eff}=1.0. An external cycle time of three years and 0.1% losses of the actinides were assumed.

Region-dependent, 33-group cross sections were generated with the MC^2-2 code [2] based on ENDF/B-V nuclear data. Beginning of cycle material compositions and temperatures were used in the MC^2-2 calculations. Hex-Z computational models were used for the whole-core calculations. The flux distributions were obtained using the finite different diffusion theory option of the DIF3D code [3].

A number of reactivity parameters were evaluated for selected cases. The reactivity parameters were calculated by using the beginning and end of equilibrium cycle (BOEC and EOEC) number densities from the REBUS-3 calculations, generating individual DIF3D cases, and utilizing new cross section sets obtained from MC^2-2 cases for the reference and perturbed conditions. The reactivity values were calculated by eigenvalue difference. This approach was used for all parameters with the exception of the axial and radial expansion calculations, where the unperturbed BOEC or EOEC cross section libraries were employed.

The delayed neutron fraction and prompt neutron lifetime were calculated for the BOEC and EOEC with VARI3D [4] using the real and adjoint fluxes calculated with DIF3D for the unperturbed conditions. The six group kinetics parameters were generated using ENDF/B-V isotopic cross section data. The VARI3D code merges the kinetics data for all regions of the reactor and generates a single set of kinetics parameters.

3. Low Conversion Ratio Gas-Cooled Fast Reactor Design Comparison

Two leading GFR concepts are evaluated for use as low conversion ratio TRU burner designs. They are 1) a block-type fuel assembly design using helium coolant, (U,TRU)C dispersion fuel, and SiC matrix and 2) a pin-type fuel assembly design using helium coolant, (U,TRU)C solid solution fuel, and Nb-1Zr alloy structure. These designs not only represent two leading concepts, but exhibit very different physics behavior. The block fuel design contains a large amount of SiC, which has low absorption cross sections and effectively moderates the neutrons. The pin fuel design uses primarily niobium for the structural material, which has a large absorption cross section and produces a much harder neutron spectrum. Fig. 1 shows the BOEC fast (> 0.1 MeV) neutron fraction as a function of conversion ratio.

For both design concepts, the power level is 600 MWt and the power density is 100 W/cc. The feed materials are TRU recycled from uranium LWR spent fuel and depleted uranium. The core design has eight rings of fuel assemblies (19 control rod locations assumed). The reference pin fuel assembly design is provided in Table 1. The block fuel assembly has the same assembly pitch and is assumed to be composed of 10% structure (SiC) and 56% coolant (He) by volume; the remainder of the block fuel assembly being the dispersion fuel (carbide fuel particles in a SiC matrix). The reference designs for both the block and pin-type fuel assemblies are based on ongoing research which is attempting to optimize the fuel volume fraction in order to reduce the core size for sustainable (CR=1) designs.

Table 1. Reference Pin Fuel Assembly Design.

Fuel Assembly Pitch (in)	6.928
Gap between assemblies (in)	0.237
Fuel Rods per Assembly	271
Duct Thickness (in)	0.100
Rod Diameter (in)	0.285
Cladding Thickness (in)	0.019
Fuel Pellet OD (in)	0.240
Average Fuel Density (% TD)	85%

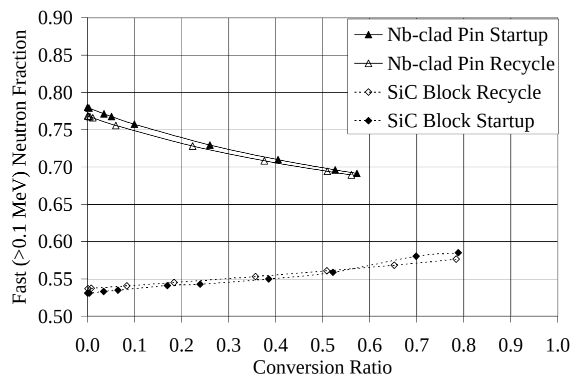

Fig. 1. BOEC Fast Neutron Fraction

A six-batch fuel management scheme was used with the cycle length varied to achieve an average discharge burnup of 10% for each design concept using its reference fuel. For the block fuel design, this corresponds to a cycle length of 431 full-power days and an average energy production at discharge of 10,336 MWd per assembly. For the pin fuel design, this corresponds to a cycle length of 522 full-power days and an average energy production at discharge of 12,528 MWd per assembly.

The evaluations considered were for the reference design and modified designs with conversion ratios ranging from the value for the reference design to zero. Two separate fuel cycles were evaluated. The first is the equilibrium fuel cycle without recycle ("startup" fuel cycle). In this case, the external feed composition is fixed and used to create all fresh fuel. The second is the equilibrium fuel cycle with the TRU elements recycled ("equilibrium recycle"). In this case, the fresh fuel is composed first of the recycle TRU, with the external feed only used as make-up. The startup core is expected to be somewhat representative of the early performance of the GFR before the system begins to approach the performance of a true equilibrium system after a fair amount of TRU has been recycled and the isotopic mix of the fuel has shifted closer to the final equilibrium composition.

The block-type fuel assemblies use dispersion fuel which allows for varying the relative quantity of fuel (dispersed particles) and the matrix without any dimensional changes to the fuel assembly. The maximum volume fraction of fuel particles may be as high as 70% in the SiC matrix, which represents the highest possible conversion ratio. The conversion ratio was varied by changing relative quantities of fuel and matrix material and maintaining all other parameters the same.

The pin-type fuel assemblies use solid solution fuel with geometric changes to the fuel assembly to adjust the fuel volume fraction. The conversion ratio was varied by reducing the pin diameter. This has the effect of increasing the coolant volume fraction, and reducing the fuel and structure volume fractions. The duct dimensions remained unchanged, which increases the relative amount of structure to fuel as the pin diameter is reduced.

Table 2 contains a summary of the reactor performance data for the block fuel GFR for conversion ratios from 0.79 (reference design) to 0.00. The fuel/matrix fraction is 18%/82% for the zero conversion ratio startup cores. The fuel volume fraction is reduced by 75% from the reference to zero conversion ratio case, while the SiC volume fraction is increased by almost 90%. Lower fuel fractions would not achieve the specified cycle length, but might be applicable for fuel cycles with shorter fuel residence times. With TRU recycle, the relatively high reactivity (high ^{239}Pu) content LWR TRU feed will be degraded at low conversion ratios. This will require a higher TRU enrichment to operate for the given cycle length. This higher TRU enrichment is the primary reason for the reduced conversion ratio for a fixed fuel volume fraction. This can be seen in the large increase in the zero conversion ratio fuel loading to 22%/78%, which is 22% increase in fuel loading from startup to equilibrium. The difference is smaller at higher conversion ratios because of the production of ^{239}Pu.

A summary of the reactor performance data for the startup case of the pin fuel GFR for conversion ratios ranging from 0.57 (reference design) to 0.00 is provided in Table 3. The fuel volume fraction is reduced by 75% from the reference to zero conversion ratio case, while the Nb volume fraction is reduced by almost 50% and the helium volume fraction increases by more than 50%. The fuel volume fraction increases by 18% for the equilibrium recycle of the case with a zero conversion ratio.

The pin design using Nb-1Zr for structural materials has a much harder neutron spectrum relative to the block fuel using SiC as the matrix and structure. Additionally, the relatively large absorption cross section of Nb relative to SiC results in a much higher parasitic absorption rate. The large differences in neutron spectrum and neutron economy explain the large differences in performance and safety parameters between the pin fuel and block fuel designs. These generally lead to more favorable results for the block fuel design. The high absorption cross section of Nb leads to a much lower conversion ratio at a given fuel volume fraction because the parasitic absorption of the Nb requires a higher TRU enrichment. Both designs have lower conversion ratios after the fuel is recycled and the TRU vector is degraded. As expected, the burnup reactivity swing increases substantially as the conversion ratio is reduced, but is similar between the two designs. The degraded TRU vector at low conversion ratios leads to lower reactivity swings for the equilibrium recycle.

Fig. 2 and 3 show the heavy metal and TRU loading versus conversion ratio at the BOEC. The parasitic absorption of Nb requires a higher fuel volume fraction to operate for the specified cycle length, which translates into larger heavy metal and TRU loadings. Degradation of the TRU vector, leads to significant increases in the TRU loading especially at low conversion ratios for the equilibrium recycle because of the relatively higher fertile content.

Table 2. Block Fuel Reactor Performance with Decreasing Conversion Ratio.

TRU Feed	Startup				Recycle			
Volume Fractions	Ref.				Ref.			
Fuel	0.240	0.172	0.103	0.062	0.240	0.172	0.103	0.075
Structure (Matrix & Structure)	0.204	0.273	0.342	0.383	0.204	0.273	0.342	0.370
Coolant	0.555	0.555	0.555	0.555	0.555	0.555	0.555	0.555
Fuel / Matrix (%)	70/30	50/50	30/70	18/82	70/30	50/50	30/70	22/78
TRU Conversion Ratio	**0.79**	**0.52**	**0.24**	**0.00**	**0.78**	**0.51**	**0.18**	**0.00**
TRU Charge Enrichment (%)	23	33	57	100	23	37	69	100
Burnup Reactivity Swing (%Δk)	1.5	3.6	6.1	8.6	1.4	3.0	5.0	6.4
Discharge Burnup	10%	14%	23%	39%	10%	14%	24%	33%
Net TRU consumption rate (kg/yr)	41	99	167	228	42	103	182	228

Table 3. Pin Fuel Reactor Performance with Decreasing Conversion Ratio.

TRU Feed	Startup				Recycle			
Volume Fractions	Ref.				Ref.			
Fuel	0.292	0.215	0.161	0.074	0.292	0.161	0.108	0.088
Structure (Cladding & Ducting)	0.157	0.130	0.111	0.081	0.157	0.111	0.092	0.085
Coolant	0.534	0.642	0.718	0.840	0.534	0.718	0.794	0.822
TRU Conversion Ratio	**0.57**	**0.41**	**0.26**	**0.00**	**0.56**	**0.22**	**0.06**	**0.00**
TRU Charge Enrichment (%)	25	33	44	100	27	51	80	100
Burnup Reactivity Swing (%Δk)	2.8	4.1	5.6	8.2	2.4	4.8	6.2	6.7
Discharge Burnup	10%	14%	18%	40%	10%	18%	28%	34%
Net TRU consumption rate (kg/yr)	86	123	157	229	88	167	212	230

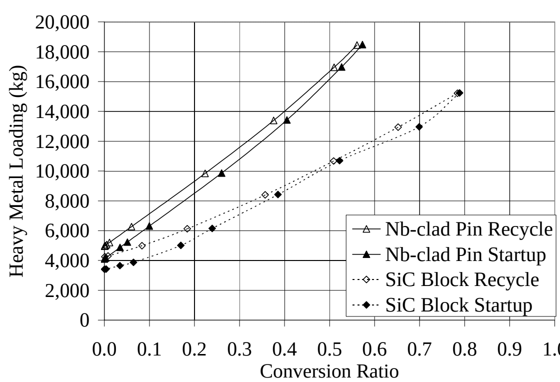

Fig. 2. BOEC Heavy Metal Loading

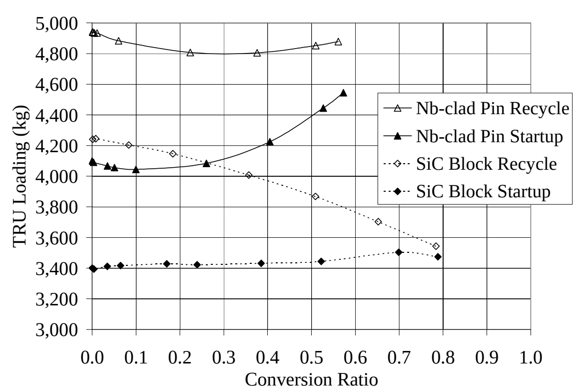

Fig. 3. BOEC Transuranic Loading

For the block fuel design, the startup and recycle cases have similar TRU loadings at CR>0.8. For the equilibrium recycle case, the TRU loading increases significantly as the conversion ratio is reduced, whereas the TRU loading decreases slightly as the CR is reduced for the startup core. There appears to be several factors that cause these trends. With TRU recycle, the TRU vector changes rather significantly and is dependent on the conversion ratio. This change includes a substantial reduction in the Pu-239 and Np-237 fractions and increases in the Pu-240, Pu-242 and higher actinide fractions. The equilibrium mix of isotopes appears to be a lower reactivity mix, which is probably made even less reactive at low conversion ratios because of the high SiC content which softens the neutron spectrum.

The opposite behavior is true for the TRU loading versus conversion ratio for the pin fuel design. It appears that the startup and recycle cases would, like the block fuel design, have similar TRU loadings at CR>0.8, except approximately 40% higher. For the equilibrium recycle case, the TRU loading varies only a few percent with over the range of conversion ratios studied, whereas the TRU loading decreases by more than 10% as the CR is reduced from 0.6 to 0.0 for the startup core. There appears to be several factors that cause these trends. The Nb (neutron absorber) content is reduced by nearly one half as the conversion ratio is reduced because the smaller diameter pins have less cladding per assembly. Calculations were performed for a constant Nb content. The results show that the TRU loading still decreases as the conversion ratio is reduced, but the magnitude is reduced by approximately two thirds; thus, the majority of the trend is attributed to reduced cladding fraction with less parasitic capture. In addition, the fast neutron fraction increases substantially as the conversion ratio is reduced (see Fig. 1), which leads to higher average neutrons per absorption (η) in TRU. For the startup core, these effects lead to reduced TRU loading as the conversion ratio is reduced. With TRU recycle the same effects apply, but the TRU vector changes rather significantly and is dependent on the conversion ratio. The change in TRU vector offsets the other effects that reduced the TRU loading in the startup core.

There are other effects that factor into the TRU loading as a function of CR for both designs. These include reduced ^{238}U, lower heavy metal density, larger discharge burnup, etc. For sodium-cooled fast reactors, the TRU loading tends to remain constant for similar conversion ratio parametric studies.

Fig. 4 displays the TRU charge enrichment versus conversion ratio. The differences are a function of neutron spectrum with all designs converging to a TRU charge enrichment of 100% at CR=0.0. Generally, the ^{238}U capture cross section increases and the TRU average fission cross section decreases with decreasing neutron energy over the energy of interest in the GFRs. Therefore, for a given TRU charge enrichment, the conversion ratio will generally be higher as the neutron spectrum is softened, which is the case between the softer spectrum of the block fuel relative to the pin fuel.

The pin fuel shows a large increase in helium void worth as the conversion ratio is reduced (see Fig. 5). This is due primarily to the increased coolant volume fraction. When normalized to the coolant volume fraction, there is still a larger helium void worth for the pin design than the block design. The difference between the pin design and block design is in large part due to the increased importance of the helium scattering in the very hard spectrum of the pin design. For both designs, the helium void worth increased with TRU recycle, especially at low conversion ratios.

Fig. 6 shows the EOEC Doppler temperature coefficient (DTC) versus conversion ratio. The large difference in neutron spectrum leads to large differences in the DTC. The more negative DTC of the block fuel design would result in very different safety characteristics between the two designs.

The variation of the EOEC delayed neutron fraction with conversion ratio is shown in Fig. 7. The delayed neutron fractions are similar between the two designs except at very low conversion ratios. At high conversion ratios both designs have significant fast fission of ^{238}U and a high content of ^{239}Pu. At low conversion ratios, there are much larger differences in the TRU vectors.

The combination of similar burnup reactivity swings, smaller helium void coefficient, larger Doppler temperature coefficient, similar delayed neutron fraction, and longer prompt neutron lifetime suggest that the block fuel design may have significantly better safety performance than the pin fuel design. The advantage for the block fuel design seems to increase as the conversion ratio is reduced. How the two designs will behave under transient conditions has yet to be evaluated and therefore a final conclusion cannot be made about the preferred design or even if either design will have acceptable safety characteristics. The differences in other performance parameters will most likely be secondary to the safety issues. Both fuel designs use unproven designs and materials that may not satisfy the operational conditions or radiation damage that was assumed.

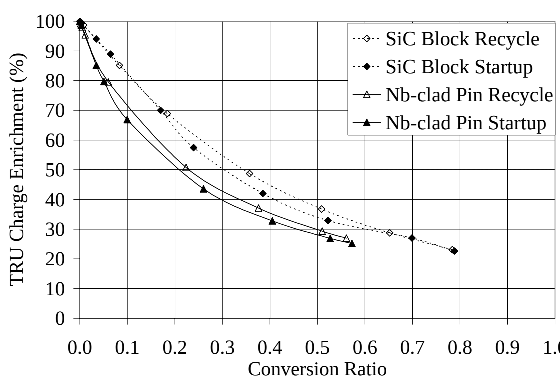

Fig. 4. TRU Charge Enrichment

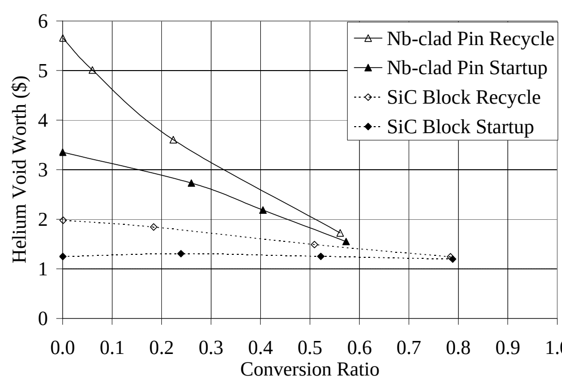

Fig. 5. EOEC Helium Void Worth

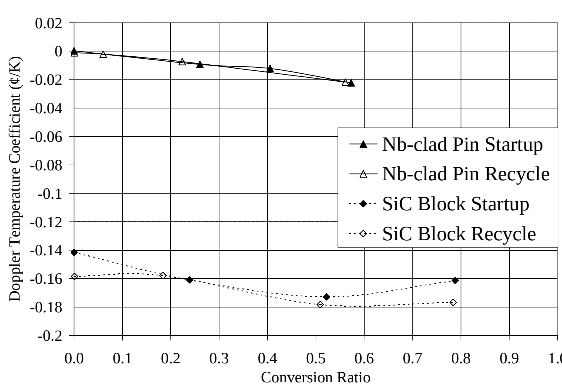

Fig. 6. EOEC Doppler Temperature Coefficient

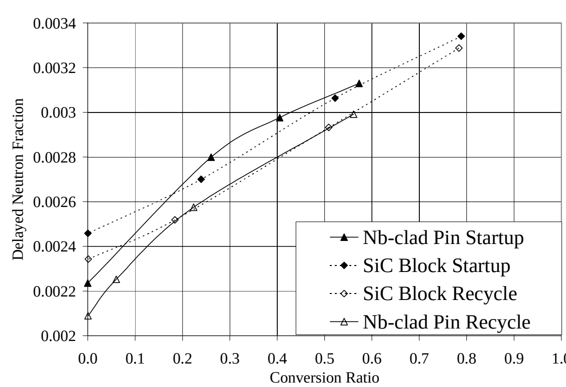

Fig. 7. EOEC Delayed Neutron Fraction

4. Fuel Cycle Parametric Studies

A number of parametric studies on the fuel cycle were performed for the block-type fuel assembly design. These studies were done for the cases with a 50/50 and 30/70 fuel/matrix ratio. These correspond to conversion ratios of 0.52 and 0.24, respectively, for the case using LWR TRU for the startup cycle. In particular, two separate partially consumed TRU feed streams were evaluated to assess the possibility of using the GFR as a second tier system. A two tier system would partially recycle the TRU in a thermal system (Tier I) followed by a complete recycle in a fast (Tier II) system. The two Tier II streams evaluated represent a single recycle of some of the TRU back into LWRs and a complete recycle of the plutonium [5] referred to as "CORAIL MA". The two additional TRU feed streams considered are a relatively high fissile content TRU feed stream and a very low fissile content minor actinide only feed stream, respectively.

The results show that the GFR can be designed to be a Tier II system, but that the performance will depend on the Tier II TRU feed stream. Since the Tier II feed streams will generally have lower fissile content TRU vectors, the enrichment at a given fuel volume fraction and cycle length will increase. This will lead to lower conversion ratios at higher fuel volume fractions. For the 30/70 fuel/matrix ratio, the fuel volume fraction is too low for the CORAIL MA feed and the reactor cannot be started with 100% TRU enrichment for this design.

The degraded TRU vectors of the TRU feed stream will also tend to reduce the burnup reactivity swing at a given conversion ratio. In fact, the very low fissile content and increased fertile fraction of the CORAIL MA feed leads to a reactivity increase over the cycle with the EOEC k_{eff} being substantially above 1.00.

Another consequence of the low fissile content feed is an increase in TRU loading. The TRU loading for the CORAIL MA feed is nearly three times as high as required for the LWR TRU feed for the same conversion ratio. The repeated recycle of this fuel would most likely significantly reduce the TRU loading required because of transmutation to more fissionable species.

The recycle of spent fuel uranium was found to have little effect on the performance of the GFR core. The use of recycled uranium results in a slight reduction in the conversion ratio. From a waste management point of view the recycle of this uranium is desirable as it minimizes the amount of heavy metal to be sent to the repository or waste burial sites.

The fuel separation process might not be able to completely separate the rare earth elements from the TRU elements. The impact of incomplete rare earth elements removal on core performance has also been evaluated. From a proliferation perspective, a high content of rare earth elements in the recycled fuel may be beneficial as it provides a radiation barrier to material diversion. The reference fuel cycle assumed 5% of the rare earth elements were recycled with the TRU. The difference in the core physics performance for the GFR cases with and without carry-over of rare earth fission products is small.

5. Comparison with Sodium-Cooled Fast Reactors

Comparison of the core performance data of the GFRs and a compact Sodium-Cooled Fast Reactor (SFR) [6] at conversion ratios of 0.0 and approximately 0.5 has been done. There are a few differences in the designs of the GFRs and the sodium-cooled reactor. The GFRs are 600 MWt and the SFR is 840 MWt. The average power density in the fuel assemblies is more than three times higher in the SFR (323 W/cc) than for the GFRs (100 W/cc).

Table 4 includes a comparison of the SFR and GFRs. The performance of the SFR generally lies between the two GFR designs with a few important differences. The higher power density of the SFR leads to a lower in-core inventory of both heavy metal and TRU. The better cooling properties of sodium allows for a higher power density, which may lead to a significant cost advantage. When normalized to power level, the net TRU consumption rate is the same for all designs. The SFR has a lower burnup reactivity swing. However, the SFR operates with a 7-batch fuel management scheme versus the 6-batch fuel management scheme of the GFR. With similar burnup and fuel management schemes, it appears that the GFR and SFR would have similar burnup reactivity swings for a given conversion ratio.

Table 4. Fast Burner Design Comparison.

	Sodium		Block		Pin	
TRU Conversion Ratio	0.50	0.00	0.52	0.00	0.57	0.00
Fuel Volume Fraction	0.30	0.12	0.17	0.06	0.29	0.07
Structure/Matrix Volume Fraction	0.26	0.35	0.27	0.38	0.16	0.08
Coolant Volume Fraction	0.44	0.54	0.56	0.56	0.53	0.84
TRU Charge Enrichment (%)	31	100	33	100	25	100
BOC HM Loading (kg)	7,485	2,521	10,695	3,405	18,476	4,105
EOC HM Loading (kg)	7,351	2,387	10,429	3,138	18,155	3,779
BOC TRU Inventory (kg)	2,254	2,521	3,444	3,400	4,545	4,099
BOC HM Loading (kg/MWt)	8.9	3.0	17.8	5.7	30.8	6.8
BOC TRU Inventory (kg/MWt)	2.7	3.0	5.7	5.7	7.6	6.8
Net TRU consumption rate (kg/MWt-yr)	0.17	0.36	0.17	0.38	0.14	0.38
Ave. Discharge Burnup (MWd/kg)	112	298	133	370	94	373
Peak Fast Fluence (10^{23} n/cm^2)	3.9	4.0	3.1	3.1	4.2	5.1
Burnup Reactivity Loss (%Δk)	2.6	5.8	3.6	8.6	2.8	8.2
BOEC						
Delayed Neutron Fraction	0.00313	0.00244	0.00309	0.00246	0.00315	0.00226
Prompt Neutron Lifetime (sec)	3.6E-07	5.2E-07	2.2E-06	4.3E-06	2.6E-07	4. 5E-07
Coolant Void Worth ($)	5.6	-1.6	1.2	1.2	1.5	2.8
Doppler Temperature Coefficient (¢/K)	-0.070	-0.001	-0.169	-0.115	-0.023	0.000
EOEC						
Delayed Neutron Fraction	0.00311	0.00247	0.00306	0.00246	0.00313	0.00224
Prompt Neutron Lifetime (sec)	3.8E-07	5.8E-07	2.1E-06	4.3E-06	2.6E-07	4.6E-07
Coolant Void Worth ($)	6.3	-0.7	1.3	1.2	1.6	3.4
Doppler Temperature Coefficient (¢/K)	-0.076	0.000	-0.173	-0.142	-0.022	0.000

Table 4 includes a comparison of reactivity parameters of a SFR with those of the GFR burners. The delayed neutron fraction, prompt neutron lifetime, and Doppler temperature coefficient for the SFR lie within the range of the GFR values. The sodium void worth is far more conversion ratio dependent than the helium void worth in the GFR. The sodium void worth ranges from a value nearly four times larger than the helium void worth for the pin fuel GFRs at CR=.5 to a negative value at CR=0. The GFR operates at 7 MPa and a significant failure of the primary coolant system could quickly reduce the pressure to atmospheric levels (0.1 MPa). The sodium system will be operated at near atmospheric pressure, which would presumably make a complete loss of coolant far less likely. Another difference is the decay heat removal capability of the systems, for which the SFR is much better than the GFRs. On the other hand, localized voiding could occur as a result of localized boiling in the sodium-cooled system, which is a phenomenon that cannot occur in the gas cooled system. From the few reactivity coefficients that were evaluated, the SFR appears likely to have a safety advantage over the GFR. The one exception could result from the much larger magnitude of the Doppler temperature coefficient for the block fuel design at very low conversion ratios.

6. Conclusions

This report examined the reactor physics and the safety characteristics of GFRs designed for low conversion ratios. A similar approach as used for the low conversion ratio SFR (e.g., reducing fuel volume fraction) [6] was effective for achieving a low conversion ratio GFR. As with the low conversion ratio SFR, low conversion ratio GFRs will have very large burnup reactivity swings that will require additional reactivity control. The low power density of the GFR, generally a disadvantage, may allow the GFR to manage reactivity by a large increase in the number of fuel batches while still retaining reasonable cycle lengths.

For the GFR, the results show that both block fuel assemblies using dispersion fuel and pin fuel using solid solution fuel are feasible options for low conversion ratio reactors. Generally, the block fuel has better performance and safety parameters. One particularly interesting result of this study was a large negative Doppler temperature coefficient for the block fuel design even at very low conversion ratios. This deserves some additional analysis to clarify its source.

The fuel design has not been finalized for either the block- or pin-fuel type GFR. Achieving sufficient fuel density using the dispersion or coated particle fuel to reach a CR of approximately one is a significant fuel design challenge. At low conversion ratios, the fuel design may be less challenging because the fuel density can be much lower. The fuel volume fraction is approximately 25% of the reference value at a CR=0.

The performance of a compact SFR was compared with the two GFR designs that were evaluated. The large differences in the two GFR designs generally bounded the results for the SFR. There are some indications that the SFR may have better safety performance because of some improvements in the reactivity parameters that were evaluated.

Parametric studies were performed to evaluate the impact of a number of fuel cycle choices. The parametric studies included the investigation of the impacts of TRU recycle, uranium recycle, partially burned TRU feed, and rare earth fission product separation. As expected in the fast spectrum, these had relatively little effect on the performance of the GFR with the exception of very low fissile content TRU feed. For a given fuel design (i.e., fixed volume fractions) and Tier I TRU feed, the repeated recycle of the TRU will lower the conversion ratio, reduce the reactivity swing, and increase the TRU enrichment and loading. Low fissile content TRU feed will increase the TRU loading, but can significantly reduce the burnup reactivity swing.

7. References

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