NEUTRONICS-PROCESSING INTERFACE ANALYSES FOR THE ACCELERATOR TRANSMUTATION OF WASTE (ATW) AQUEOUS–BASED BLANKET SYSTEM

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ABSTRACT

Neutronics-processing interface parameters have large impacts on the neutron economy and transmutation performance of an aqueous-based Accelerator Transmutation of Waste (ATW) system. A detailed assessment of the interdependence of these blanket neutronic and chemical processing parameters has been performed. Neutronic performance analyses require that neutron transport calculations for the ATW blanket systems be fully coupled with the blanket processing and include all neutron absorption in candidate waste nuclides as well as in fission and transmutation products. The effects of processing rates, flux levels, flux spectra, and external-to–blanket inventories *on* blanket neutronic performance were determined. In addition, the inventories and isotopics in the various subsystems were also calculated for various actinide and long-lived fission product transmutation strategies .

INTRODUCTION

Transmutation of long-lived nuclear waste (transuranic actinides and long–lived fission products) currently stored in spent reactor fuels may represent an attractive alternative to deep geologic disposal. A transmutation reaction is defined as a fission reaction for an actinide and a capture reactions to stable or short–lived product for a long–lived fission product (LLFP) . The long–lived fission products are defined as those with half-lives greater than 30 years. The transuranic actinides present in spent reactor fuel are Np. Pu, Am, Cm, and very small amounts of Bk and Cf; the LLFPs are ^{79}Se, ^{93}Zr, ^{99}Tc, ^{107}Pd, ^{126}Sn, ^{129}I, and ^{135}Cs. Some of these LLFPs pose very low biological/environmental risks and thus, the selection of LLFP nuclides requiring transmutation, referred to as the LLFP transmutation strategy, is not well defined.

The Los Alamos developed aqueous-based Accelerator Transmutation of Waste (ATW) concept uses a proton accelerator to produce a 1.6 GeV, 250 mA beam that is split four ways to strike one of four D_2O-cooled solid tungsten–lead composite targets. This interaction generates tens of neutrons per incident proton, resulting in an intense neutron source from the target. Waste material to be irradiated is located in a D20-moderated blanket region which surrounds the target. Neutrons are moderated to enhance their probability of capture and are multiplied via fission, producing high neutron fluxes. The high thermal flux allows large transmutation reaction rates at low material inventories in the blanket. The high burn rates per system inventory allow both rapid reduction of long–lived nuclear waste inventories and low residual end-of-life inventories. The transuranic actinides are introduced to the blanket region in flowing actinide oxide-D_2O slurry loops . The slurry tube lattice acts as a subcritical nuclear assembly and carries the fission energy out of the blanket to a heat exchanger[1] . The LLFPs are irradiated in separate blanket loops. The fission energy recovered from the blanket is converted to electric power using conventional nuclear power conversion systems. A small fraction (20-25%) of this power is required for the accelerator, so that considerable power is available from the ATW system to the electric grid.

Both actinide slurry and LLFP loops include continuous slip–stream feed and recovery for processing. This feature provides the necessary processing flexibility required to maintain low parasitic capture in transmutation products. The higher transuranic actinides and major long-lived fission product nuclides produced by transmutation of the actinides are recovered in processing and recycled to the blanket for transmutation. The transmutation rate requirements for an ATW system are based on the system transmutation capacity (i.e., the number of reactors whose waste can be transmuted) and the LLFP transmutation strategy adopted. The baseline ATW system[2] transmutes the actinides as well as the fission products

^{99}Tc and ^{129}I (as elemental iodine) from about eight LWRS.

BLANKET PERFORMANCE AND NEUTRON ECONOMY

The primary neutronic performance goals for the ATW blanket are 1) large transmutation rates with the lowest possible system inventories and 2) high neutron multiplication via fission to reduce the required source strength. In order to maximize transmutation rates and minimize the blanket inventories, it is necessary to produce high thermal neutron flux levels which are dependent primarily on achieving high neutron multiplication and low parasitic capture in the system. Achieving high neutron multiplication is dependent on a variety of factors including a high actinide fission rate, a low actinide capture-to-fission ratio, and low non-actinide capture in the system. Similarly, these factors are also dependent on various design parameters; the actinide fission rate depends on moderation of the neutron spectrum in the slurry lattice; a low capture-to-fission ratio in the actinides requires low external-to-blanket inventories and high flux levels; and low parasitic capture is achieved through minimizing capture in the target and structure of the blanket, as well as incorporating high product removal rates. The external-to-blanket inventories can be minimized by reducing the heat exchanger inventory as well as the holdup and processing inventories to the lowest possible levels.

The neutron multiplication achieved through fission in the actinide-bearing slurry lattice is the parameter which drives essentially all blanket performance and is thus used as a primary figure-of-merit for the system. The number of neutrons available for transmutation is given by the product of the accelerator current (protons per see), the target yield (neutrons per proton), and the source neutron multiplication of the blanket assembly, M. For the solid tungsten-lead target, the target yield is essentially a function of proton energy only. Thus for a specified transmutation requirement, the accelerator requirements (beam energy and current) are determined by the achievable value of M for the blanket and lattice assembly. Because the accelerator is a dominant system cost driver[3], source neutron multiplication is a critical system performance parameter. The parameter M is defined as $1/(1-k^{s}_{eff})$, k^{s}_{eff}, the effective source-driven lattice fission multiplication, is given by

$$k^{S}_{eff} = \frac{\nu}{1 + \alpha_A + \alpha_{FP} + \alpha_{LLFP} + \alpha_{TP} + \alpha_S + \alpha_L} \quad (1)$$

where α_A is the capture-to-fission ratio for the actinides, α_{FP} is the ratio of slurry fission product captures to actinide fissions, α_{LLFP} is the ratio of the LLFP captures to actinide fissions, aTp is the ratio of the LLFP transmutation product captures to actinide fissions, α_S is the ratio of the target-blanket structure captures to actinide fissions, and α_L is the ratio of target-blanket leakage to actinide fissions. The four parameters α_A, α_{LLFP}, α_{FP}, and α_{TP} are all strongly dependent on both blanket neutronic parameters such as flux level and energy spectrum as well as chemical processing parameters such as processing rates and cooling times.

CALCULATIONAL METHODOLOGY

Most of the ATW blanket neutronic performance analyses were based on the assumption that the system is at steady-state and in neutronic equilibrium. Four isotopic mixes are modeled in the transport calculations as equilibrium "lumps" calculated as averages of the isotopic mix; they are 1) the actinide lump, 2) the parasitic fission-product lump in equilibrium with the actinides, 3) the LLFP lump in equilibrium with the actinides, and 4) the parasitic transmutation-product lump in equilibrium with the LLFPs. Isotopic production/depletion calculations used the code 0RIGEN2;[4] this code allows complex feed, irradiation, cooling, and processing strategies to be modeled in either continuous or batch mode. Equilibrium isotopics were calculated using both spectrum-averaged neutron cross section from transport calculations and 0RIGEN2 library values. Neutron transport calculation for the target-blanket system were performed with the three-dimensional, continuous-energy Monte Carlo transport code MCNP5 in order to represent the heterogeneity of the system design. The four lumps were included in the MCNP calculations in different ways; each actinide was included explicitly in the slurry mixture, the fission-product lump was included in the slurry mixture as a fictitious species with an equivalent macroscopic cross section, and the LLFP and transmutation product lumps were included in the LLFP loops/regions as ^{99}Tc with an equivalent macroscopic cross section. Because the flux levels, flux spectrum, and the actinide spectrum-averaged cross sections were used to calculate the lumped parameters, an iterative calculational approach was used.

Two additional codes were written to calculate lumped equilibrium parameters for the actinides and LLFPs as well as lumped parameters for the actinide fission products and LLFP transmutation products. One code (TRANEQI) treats the two equilibrium lumps in the slurry (i.e., the actinides and the fission products). This code solves for an equilibrium actinide lump using specified isotopic feed, spatially- and spectrally-averaged one-group cross sections and slurry lattice neutron flux calculated in MCNP, and element-specific residence times external to the blanket lattice. In addition, TRANEQI interpolates within tabular capture-per-

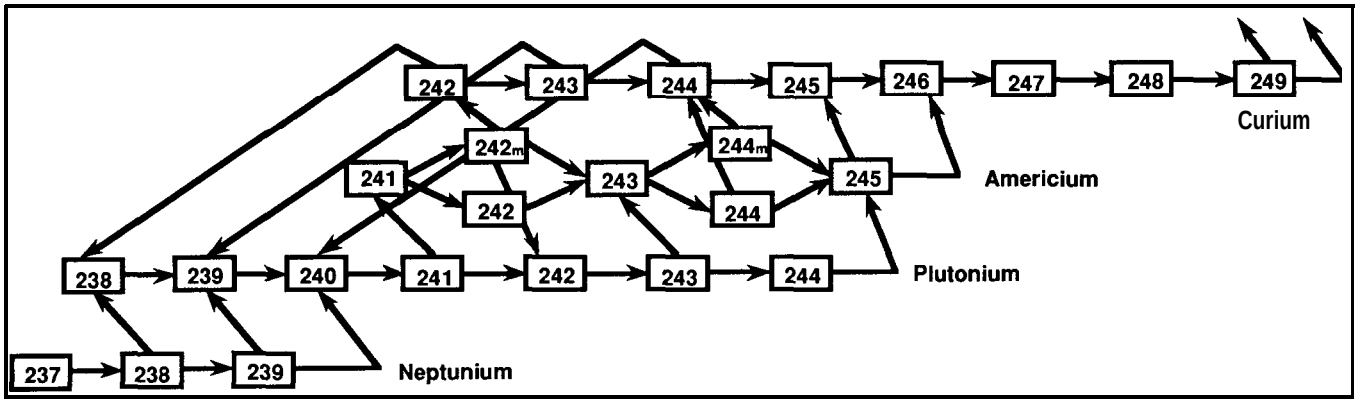

Figure 1 Actinide chain used in calculation of the equilibrium actinide "lump".

fission data (calculated with 0RIGEN2) to obtain the value for a lumped parasitic fission product in equilibrium with the equilibrium actinide lump. This data is tabulated as a function of flux level in the irradiation loop (blanket lattice plus external heat exchanger) and the time to process the actinide irradiation loop inventory for fission product removal.

The code (TRANSFP) calculates equilibrium lumped parameters for the LLFPs and the transmutation products in LLFP blanket loops. TRANSFP includes equilibrium chains for each of the seven LLFP candidates mentioned above. The LLFP lump is specified by the LLFP transmutation strategy selected for the ATW system. The LLFP strategy is defined by 1) the number of LLFPs to be included, 2) whether either or both external LLFP feed and internal LLFP production (from actinide fission) are included, and 3) whether the LLFP is fed/recycled for irradiation in its isotopic or elemental form. This code solves for an equilibrium LLFP lump using the spatially- and spectrally-averaged neutron flux calculated in MCNP for the LLFP loops, a specified external isotopic feed, and an internal feed (recycle from actinide fission) consistent with the production and processing recovery rates in the actinide slurry . TRANSFP interpolates within tabular production per fission data calculated with ORIGEN2 for each of the LLFP chain isotopes; this data is tabulated as a function of flux level in the irradiation loop and time to process the actinide irradiation loop inventory. The cross sections used were those provided with the ORIGEN2 code package for a CANDU reactor using slightly enriched uranium fuel. In addition, TRANSFP interpolates within tabular transmutation product capture per LLFP capture data calculated with ORIGEN2 to obtain a value for a lumped parasitic transmutation product. This data is tabulated as a function of average flux level in the LLFP blanket loops, the time to process the LLFP loop inventory for transmutation product removal, and irradiation time. This latter parameter was used because true equilibrium for the extensive transmutation product chains is not reached in practical irradiation times.

EQUILIBRIUM ACTINIDES

The equilibrium actinide "lump" was calculated using TRANEQI for an 25-actinide chain shown in Fig. 1. The equilibrium chains in the very thermal ATW spectrum were constructed including only capture and fission reactions . The chains were terminated at nuclides with half lives on the order of hours or less with an end-chain capture plus beta decay modeled as a capture to the ultimate daughter. All decay paths were included with out-of-chain decay tabulated separately with curium capture to berkelium. The feed isotopics used was that calculated for Np, Pu, Am, and Cm in spent LWR reactor fuel. Specifically, the 0RIGEN2 calculation was for the reference 3.2% enriched uranium-fueled PWR provided with the ORIGEN2 code package. 'The fuel was irradiated to 33 GW-days/MTIHM at a specific power of 37.5 MW/MTHIM and cooled for a period of 10 years following discharge.

Table 1 Actinide annual transmutation requirements per LWR supported.

Actinide Isotope	kg/yr per LWR
^{237}Np	14.67
^{238}Pu	4.57
^{239}Pu	168.13
^{240}Pu	77.47
^{241}Pu	25.63
^{242}Pu	15.70
^{241}Am	16.77
^{242m}Am	0.02
^{243}Am	3.02
^{243}Cm	0.01
^{244}Cm	0.59
^{245}Cm	0.03
Total	326.60

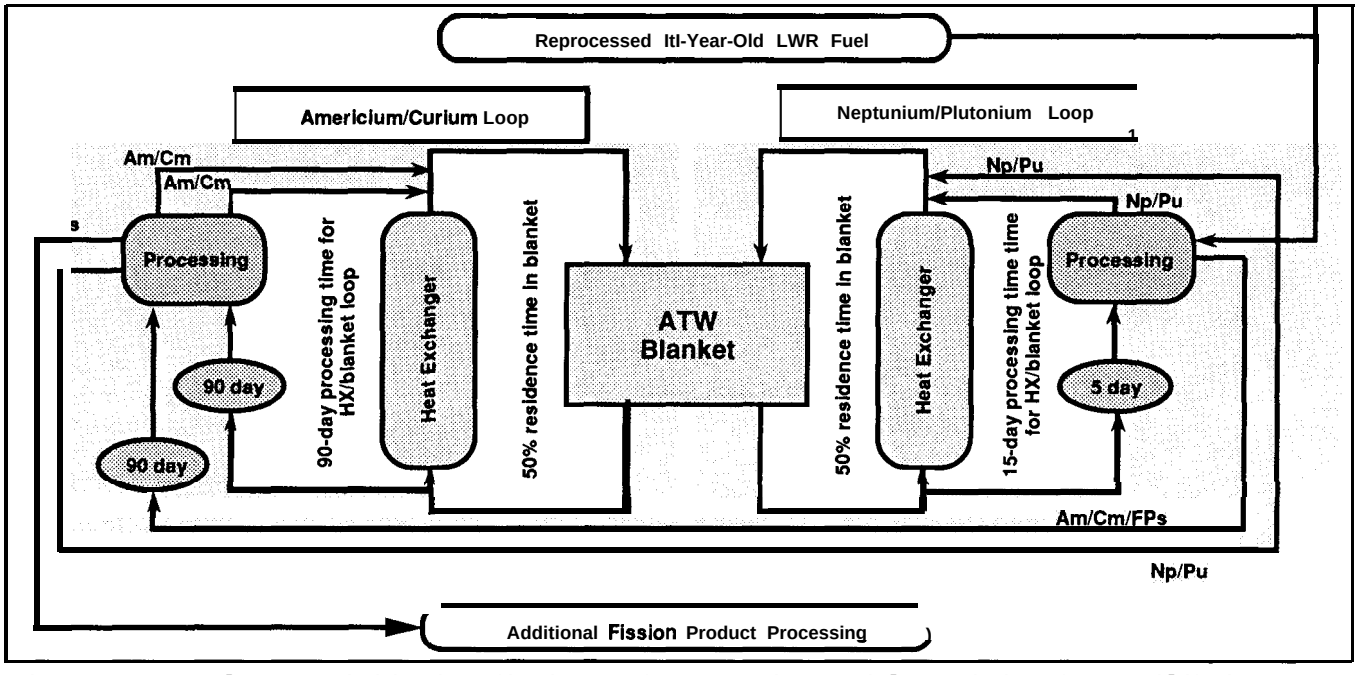

Figure 2 Two-loop actinide irradiation and processing model used in the equilibrium actinide lump calculation.

The annual transmutation requirements per LWR supported are given in Table 1.

In order to achieve low actinide inventories in the ATW system, high average fluxes must be maintained. All time spent in loops outside of the neutron flux of the blanket slurry lattice reduces the average flux seen by the actinides. The fluxes used in the TRANSEQI calculation are element specific average values which include the time that an element spends outside of the lattice. The time outside the blanket includes both the time in the heat exchanger (HEX) for the flowing slurry and also the time in cooling and fission-product recovery processing before being recycled to the irradiation loop. For the baseline ATW slurry thermal-hydraulic system, the fraction of time the slurry spends out of the lattice in the HEX systems is 0.5. The average flux in the irradiation loop (ϕ_I) is therefore 50% of the value for the average flux in the actinide slurry lattice (ϕ_A).

Two separate actinide loops are used for ATW irradiation and processing (shown in Fig. 2), a Np/Pu loop and a Am/Cm loop. Radiation damage sensitivity in the process which separates the fission products from Am and Cm produces a requirement for a 90-day cooling time in this loop. 'The liquid ion-exchange process for separation of the Np and Pu from the Am, Cm, and fission products requires only a 5-day cooling period.

The time required to process the actinide inventory in the irradiation loop for fission product recovery (τ_A) is a critical parameter in determining both the average flux seen by the actinides and also the parasitic capture in the fission products resident in the actinide slurry. One requirement for this processing parameter is based on the assumption that there is no need to maintain a lower parasitic absorption in either of the two actinide loops relative to the other. Therefore, the processing rate in each of the two loops will be proportional to the fission rate in that loop. The absolute processing rate is determined by the allowable parasitic fission product absorption α_{FP}. For the baseline ATW system, the time to process the Np/Pu inventory is 15 days and the time to process the Am/Cm inventory is 90 days; determination of this parameter is discussed below. These numbers are used to calculate a time in processing (out of the irradiation loop) of 0.25 and 0.50 for the actinides in the Np/Pu and Am/Cm loops, respectively.

Because the current blanket actinide slurry lattice design concept does not differentiate between the two actinide processing/flow loops, the actinides are treated as a single lump. A single lump-average value of τ_A is defined as a fission rate weighted average for the two loops. For the baseline ATW system, this value is ~30 days.

The equilibrium actinide isotopics calculated with TRANEQI using the LWR feed and the element-specific loop-average fluxes are shown in Fig. 3 for the baseline ATW system. Note that the fractional time in processing is denoted as 0.25-0.50 to represent the two-loop, element-specific model used. The spatially- and spectrally-

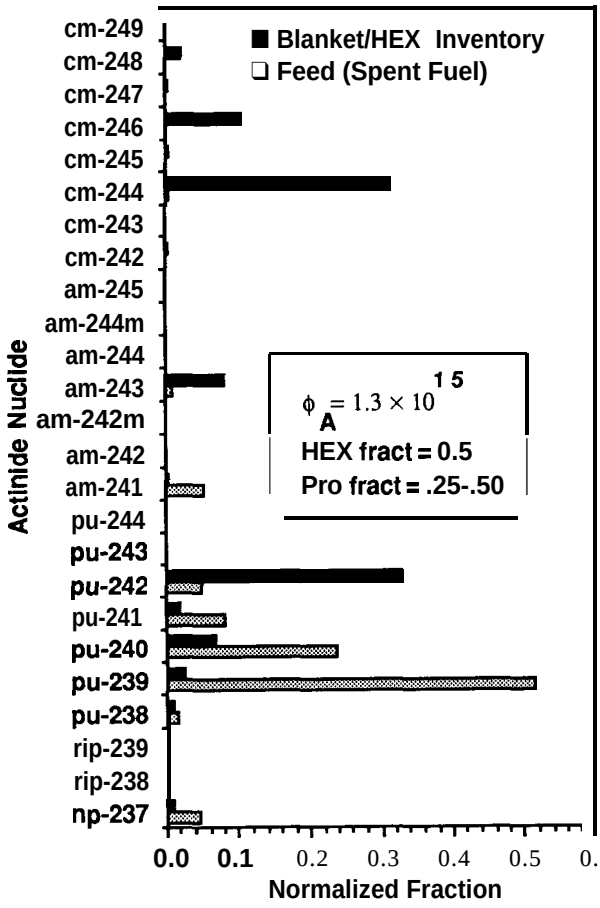

Figure 3 Feed and equilibrium irradiation loop isotopics calculated for the baseline ATW system.

averaged blanket lattice flux for this system is 1.3×10^{15}; this value is assumed to be the same for both actinide loops. Note that there is a significant shift in the feed isotopics which are dominated by ^{239}Pu and ^{240}Pu to the equilibrium isotopics which includes significant amounts of ^{242}Pu, ^{244}Cm, and ^{244}Cm.

ACTINIDE CAPTURE-TO-FISSION RATIO

The actinide capture-to-fission ratio (α_A) is calculated with TRANEQI as the ratio (in the irradiation-loop) of the macroscopic capture and fission cross section for the equilibrium lump. The value of α_A decreases with increasing flux due primarily to increased branching (versus decay) to shorter-lived actinides with large fission cross sections (e.g., ^{238}Np and ^{242}Am). This effect is shown in Fig. 4 where the effects of external-to-blanket inventories are also illustrated. The net effect of a 0.50 slurry residence time fraction in the HEX is a reduction in the flux by a factor of 2. Similarly, the 0.25 and 0.50 cooling-

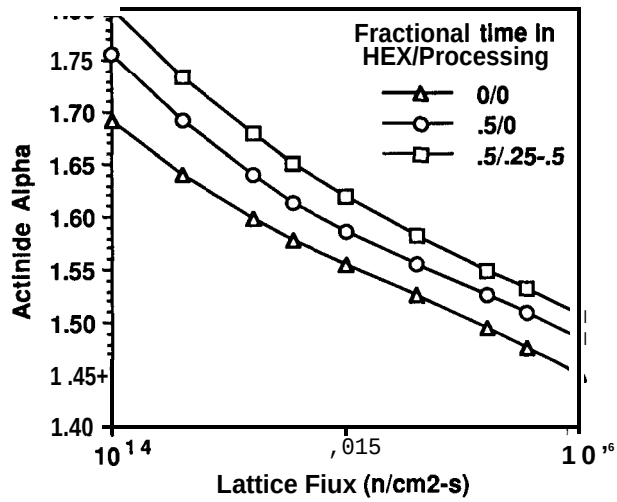

Figure 4 Actinide alpha (α_A) for the 25-actinide equilibrium lump as a function of slurry lattice average flux and fractional time outside of the blanket.

processing time fraction for the Np/Pu and Am/Cm loops also increases the lump-average value for α_A. The value of v also increases gently with flux because the isotopics shift toward curium at the higher fluxes. The larger concentrations of higher-mass actinides yields a larger lump-average value for V. For the baseline ATW system the actinide lump-average value for v is 3.0451.

PARASITIC FISSION PRODUCTS

The parasitic loss of neutron to fission product absorption in the actinide slurry can have a large impact on neutron economy. At high neutron flux levels in the ATW system, this loss channel can greatly decrease the overall neutron economy of the blanket unless the fission product removal rate is also high. Thus the need for high source neutron multiplication translates to a requirement for an actinide inventory processing time (τ_A) determined by the design flux level.

Parasitic fission product absorption is parametrically expressed in the value of α_{FP} defined in Eqn. 1 for an equilibrium fission product lump. This parameter is a function of the average flux level and spectrum in the actinide slurry as well as the processing removal rate for the fission products from the slurry. Equilibrium values for α_{FP} were calculated with ORIGEN2 using the continuous feed and processing calculation options. Calculations were performed for specified ϕ_A and τ_A values using LWR spent fuel feed isotopics, actinide σ_f and σ_c values calculated with MCNP for the baseline slurry lattice, and all other cross sections taken for the ORIGEN2 CANDU/slightly enriched uranium library. The dependence of α_{FP} on ϕ_A and τ_A is shown in Fig. 5; note that although α_{FP}

is plotted versus the lattice flux level ϕ_A, the actual flux level used in the 0RIGEN2 calculations is the irradiation-loop-averaged value.

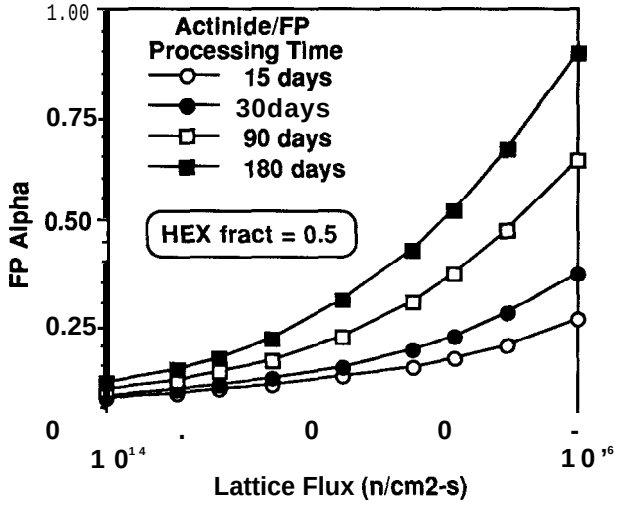

Figure 5 Slurry fission product alpha (α_{FP}) for the fission products in equilibrium with the actinide lump as a function of slurry lattice average flux and the time to process the actinide inventory.

Although the value of the actinide lump capture-to-fission ratio (α_A) decreases with increasing flux level, at a fixed slurry processing rate the sum $\alpha_A + \alpha_{FP}$ (which is an effective value of a for the slurry mixture) begins to increase at higher flux levels due to the build-up of fission products. This effect is illustrated in Fig. 6.

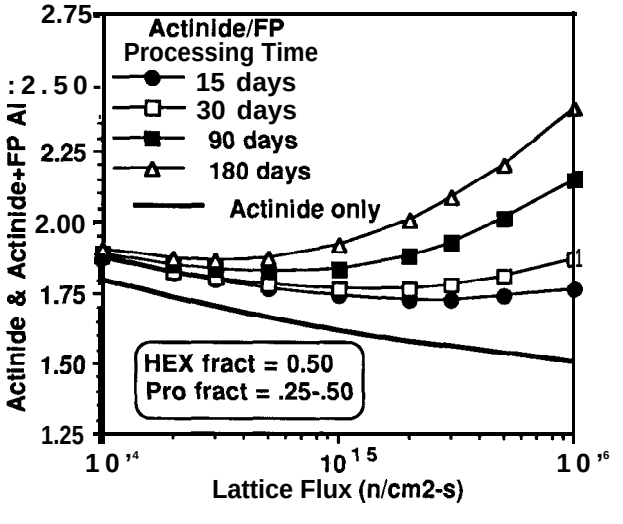

Figure 6 Sum of actinide and slurry fission product alphas ($\alpha_A+\alpha_{FP}$) for the equilibrium actinide and fission product lump as a function of slurry lattice average flux and the time to process the actinide inventory.

Note that for the average baseline actinide inventory processing time of 30 days, a minimum value for $\alpha_A + \alpha_{FP}$ is achieved at lattice flux levels in the range of 1-2x10^{15} n/cm^2-s. The effects of external inventories on aA + α_{FP} is shown in Fig. 7. The effect on $\alpha_A + \alpha_{FP}$ of the time in external processing is primarily that of a small reduction α_A in the lower average flux; however at higher flux levels, the time in the HEX has a large impact on α_{FP} because of the lower average fission rate in the irradiation loop. While these effects are most dramatic for high flux levels, significant variation in neutron multiplication occurs over the range for blanket design flux levels.

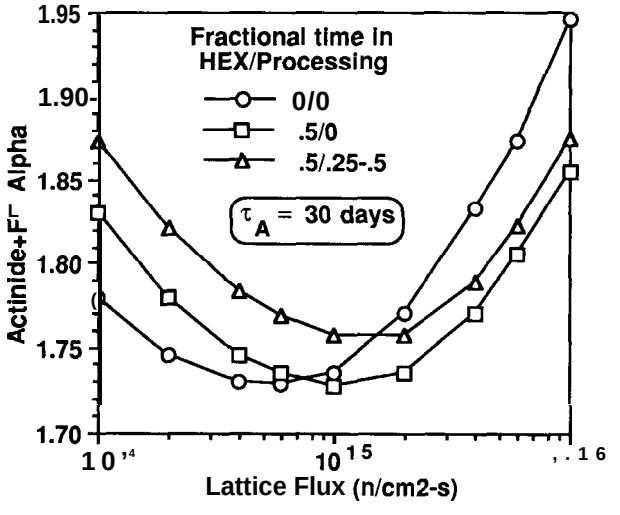

Figure 7 Sum of actinide and slurry fission product alphas ($\alpha_A+\alpha_{FP}$) for the equilibrium actinide and fission product lump as a function of slurry lattice average flux and fractional time outside of the blanket.

EQUILIBRIUM LONG-LIVED FISSION PRODUCTS

The equilibrium isotopics of the LLFP were calculated with TRANSFP as a function of LLFP transmutation strategy. The baseline ATW system includes both ^{9}9Tc and ^{129}I in their elemental form, although ^{99}Tc is naturally a single isotope. Also, both external (from LWR spent fuel) and internal feeds are included. Another case has been examined in which ^{79}Se (elemental), ^{126}Sn (elemental), and ^{135}Cs (isotopic) are also included. The external transmutation requirements for all of the seven LLFPs are presented in Table 2.

TRANSFP was used to calculate both elemental and lump-averaged values. The external feed isotopics used were those calculated 0RIGEN2 for reference spent LWR reactor fuel as described above for the actinides . The internal feed/recycle was based on the 0RIGEN2 calculations for α_{FP} described above. In each calculation the

Table 2 Long-lived isotopic and elemental fission product annual transmutation requirements per LWR supported.

LLFPIsotope and Element	kg/yr per LWR
^{79}Se	0.20
Selenium	1.88
^{93}Zr	23.95
Zirconium	120.66
99 Tc-99	25.69
Technetium	25.69
^{107}Pd	7.27
Palladium	45.72
^{126}Sn	0.91
Tin	5.79
^{129}I	5.96
Iodine	7.81
^{135}Cs	10.00
Cesium	79.40

required LLFP internal recycle transmutation rate was calculated as the product of τ_A and the equilibrium irradiation-loop inventory for the specific LLFP chain nuclide following a 90-day decay. The LLFP internal recycle transmutation requirements were thus constructed as a function of LLFP transmutation strategy, slurry lattice flux level (ϕ_A), and actinide inventory processing time (τ_A). The production of ^{1271}, a stable fission product isotope in the ^{129}i transmutation chain, is representative of most LLFP chain nuclides and is shown in Fig. 8.

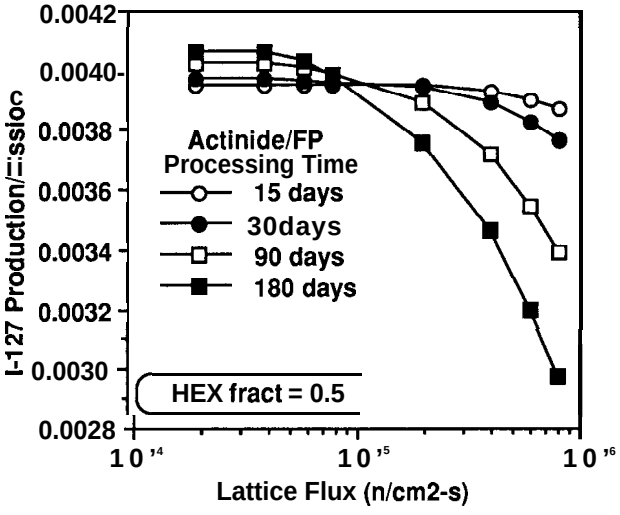

Figure 8 production of 1271 from fission in the actinide lump as a function of slurry lattice average flux and the time to process the actinide inventory.

Note that production falls off both with increasing flux level and increasing processing time. This occurs because the specific isotope is being transmuted in-situ in the slurry. The overall blanket impact on neutron economy for lower production is not necessarily good because the net effect is an increase in the value of α_{FP} for the slurry.

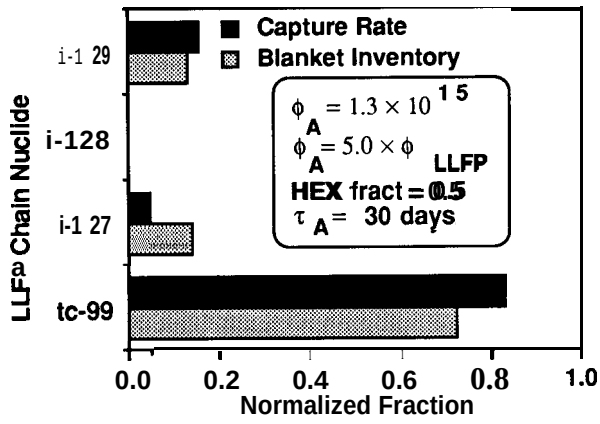

Figure 9 LLFP chain normalized isotopics and burn rates calculated for the baseline ATW system.

The relative blanket inventory isotopics and transmutation rates calculated with TRANSFP for the baseline LLFP strategy are shown in Fig. 9. The average flux level in the LLFP (technetium and iodine) blanket regions is taken to be a factor of 0.2 times that in the slurry lattice. This is an average for the baseline blanket design and the actual flux level in the various LLFP blanket regions is very geometry and design dependent. Because of the simplicity of the technetium (one nuclide) and iodine (3 nuclides) chains, the isotopic inventories are proportional to the feed (and burn) rates . The strategy which includes the more complex chains of selenium (7 nuclides), tin (16 nuclides), and cesium (5 nuclides) results in the equilibrium inventory and capture rate isotopics shown in Fig. 10. Note that the inventory is dominated by low cross section, stable selenium and tin isotopes. However based on neutron economy considerations , the transmutation performance is still good since the capture is dominated by ^{99}Tc, ^{129}I, and ^{135}Cs.

LONG-LIVED FISSION PRODUCT CAPTURES PER FISSION

The dependence of α_{Tc99} and α_{LLFP} on LLFP loop flux level and actinide inventory processing time is shown in Figs. 11 and 12, respectively. These values would actually exhibit only a relatively weak dependence on the flux level in these regions if the flux level were independent of a constant flux level in the actinide slurry lattice. However, such an independence is difficult

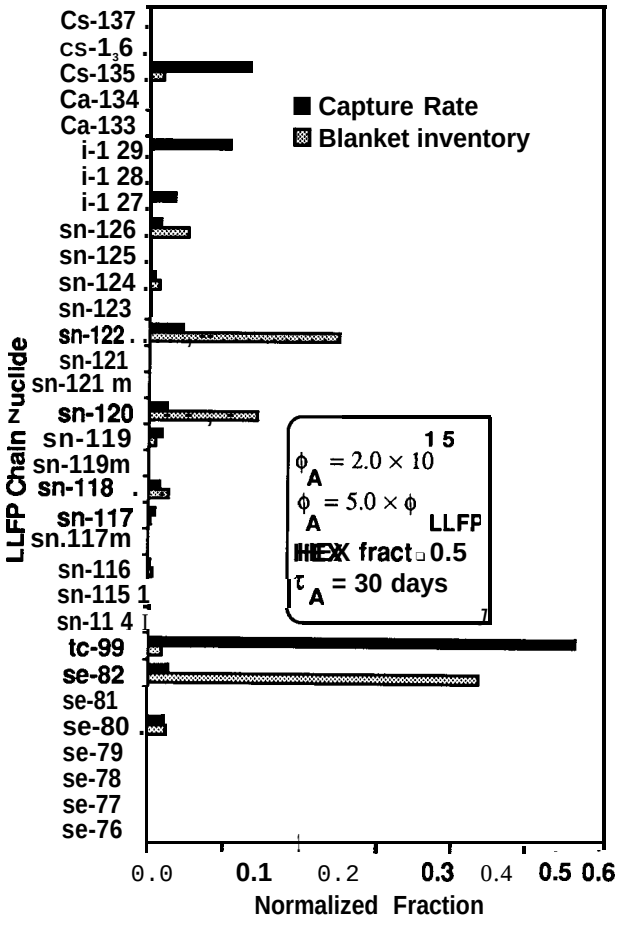

Figure 10 LLFP chain normalized isotopics and burn rates calculated for an advanced LLFP transmutation strategy.

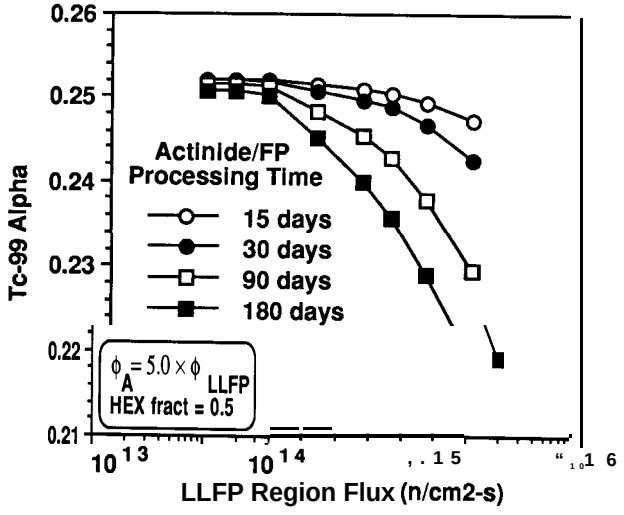

Figure 11 99Tc equilibrium lump alpha (α_{Tc}) as a function of LLFP region average flux and the time to process the actinide inventory.

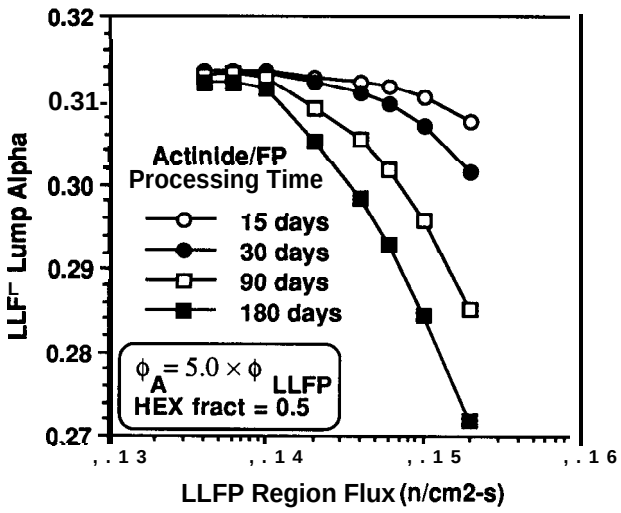

Figure 12 Long-lived fission product equilibrium lump alpha (α_{LLFP}) for the baseline ^{99}Tc/Iodine transmutation strategy as a function of LLFP region average flux and the time to process the actinide inventory .

if not impossible to achieve in the integrated ATW blanket design conce'pts under investigation. Thus α_{LLFP} depends strongly on the flux level in the LLFP loops which in turn is approximately 0.2 time that in the slurry lattice based on MCNP blanket calculations. The α_{LLFP} dependence on flux level and actinide processing rate is predominantly determined by the isotopic feed rates from actinide fission discussed above .

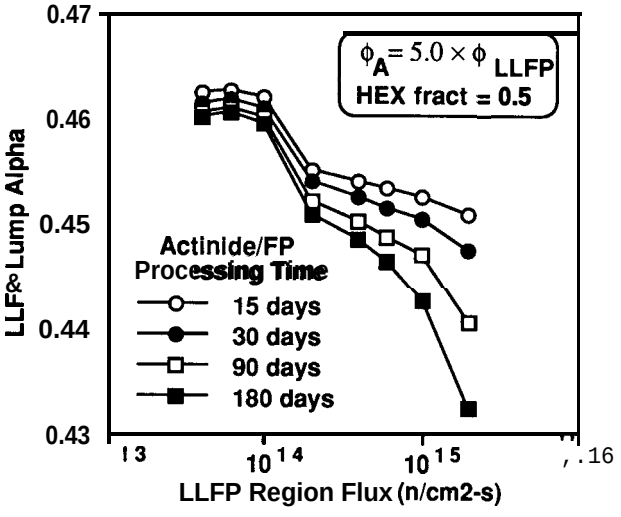

Figure 13 Long-lived fission product equilibrium lump alpha (α_{LLFP}) for an advanced LLFP transmutation strategy as a function of LLFP region average flux and the time to process the actinide inventory.

The value of α_{LLFP} also depends strongly of the LLFP transmutation strategy assumed for the system. The dependence on

flux level and processing rate of α_{LLFP} for the five-LLFP strategy is shown in Fig. 13. Note that at the baseline flux levels and processing rates, the value for α_{LLFP} is about 50% greater than that for the baseline system.

TRANSMUTATION PRODUCTS

The lumped value of α_{TP} is calculated as the sum of the values for each of the LLFP candidates. These values in turn are calculated as the product of the capture per fission value for that chain times a capture ratio r. This latter value is defined as the ratio of captures in all transmutation products (other elements) from that LLFP candidate chain to captures in the chain nuclides. This value is usually dominated by the capture in isotopes of the next higher (Z+1) element (e.g., ruthenium for technetium and xenon for iodine) .

These values were calculated with ORIGEN2 as a function of the average flux level in the LLFP loop and the LLFP inventory processing time . 0RIGEN2 calculations used the continuous feed and processing options with a feed rate of 1.0 gram-atom per second total at the baseline LLFP chain nuclide feed (external plus internal) isotopics. Calculations were performed for both isotopic and elemental feed to each of the seven LLFP candidate chains; the irradiation time was taken to be 50 years. Although isotopic equilibrium is not achieved for all chains in this time, the capture-to-capture ratio has reached equilibrium in all but a few cases. For the baseline ^{99}Tc/Iodine strategy, equilibrium is reached in 1–5 years. The values of r for and iodine calculated with ORIGEN2 are shown in Figs. 14 and 15, respectively.

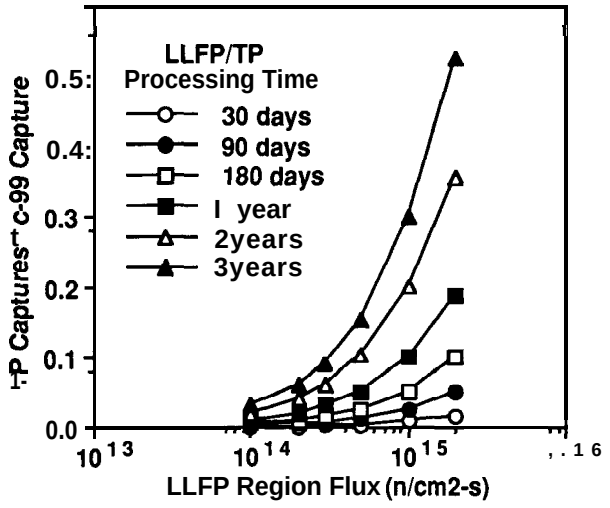

Figure 14 Ratio of ^{99}Tc transmutation product capture to ^{99}Tc captures as a function of LLFP region average flux and the time to process the ^{99}Tc inventory.

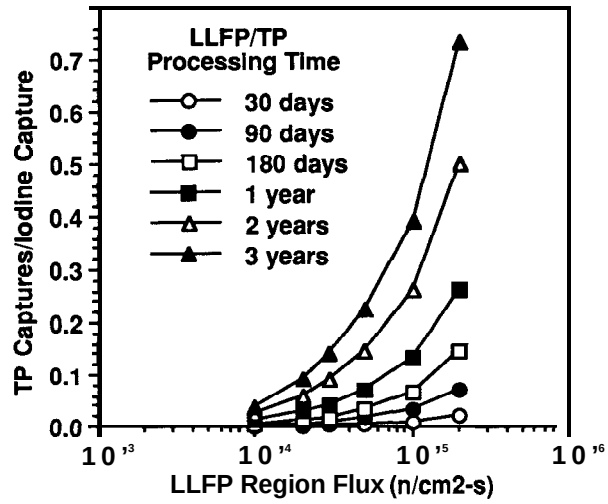

Figure 15 Ratio of iodine transmutation product capture to iodine captures as a function of LLFP region average flux and the time to process the iodine inventory.

The lumped value of α_{TP} for the baseline ^{99}Tc/Iodine strategy is shown in Fig. 16 as a function of LLFP loop flux and LLFP inventory processing time. Note that the baseline average actinide inventory processing time of 30 days has been used to generate the internal LLFP feed rate for the α_{LLFP} calculation.

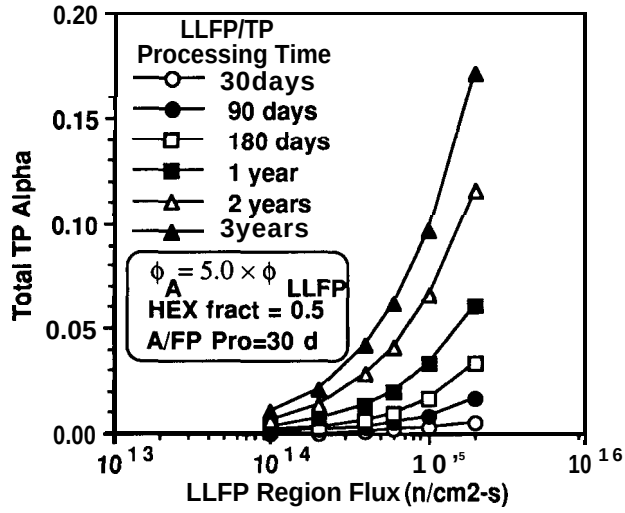

Figure 16 LLFP transmutation product equilibrium lump alpha (α_{TP}) for the baseline ^{99}Tc/Iodine strategy as a function of LLFP region average flux and the time to process the LLFP inventory.

The lumped value of α_{TP} for the advance 5-LLFP strategy is shown in Fig. 17 as a function of LLFP loop flux and LLFP inventory processing time. Note that this value does not vary significantly for that for the baseline LLFP strategy. This is because (see Fig. 10) most of the capture is

still dominated by ruthenium from the ^{99}Tc chain and xenon for the iodine chain.

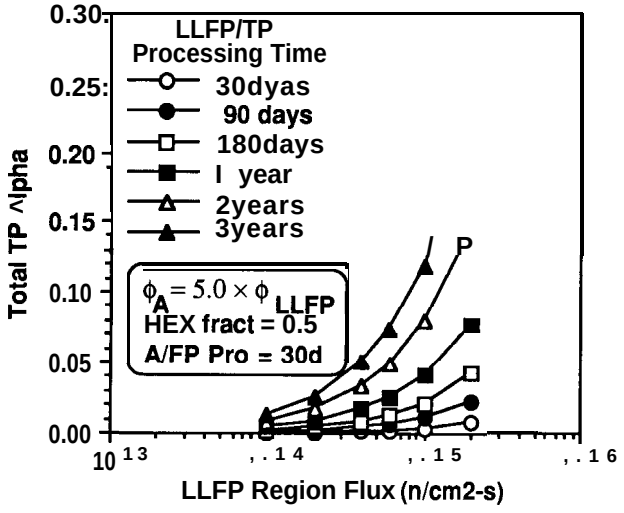

Figure 17 LLFP transmutation product equilibrium lump alpha (α_{TP}) for an advanced LLFP transmutation strategy as a function of LLFP region average flux and the time to process the LLFP inventory.

CONCLUSION

The results of the lumped parameter calculations for α_A, α_{FP}, α_{LLFP}, and α_{TP} are summarized in Table 3 for the baseline ATW blanket/processing system. These results are for a requirements-driven, fully consistent, spatially-independent model and may differ somewhat from the values which were modeled/achieved in the three-dimensional, heterogeneous transport model reported[2] elsewhere at this conference.

Table 3 lumped parameter summary for the baseline ATW blanket/processing system

Lumped Parameter	Value
α_A	1.0133
α_{FP}	.1521
α_{LLFP}	.3i 16
α_{TP}	.0007

If the values of α_S and α_L from that analysis (.1752 and .0508, respectively) are used with the above values and the actinide lump-average ν value of 3.0451 in Eqn. 1, k^S_{eff} has the value 0.9245. This corresponds to a blanket source neutron multiplication M of 13.25. Cost-based systems performance analyses[3] indicate that multiplication in the range of 10-20 will be required for economically attractive ATW systems.

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