

Radiotoxicity Characterization of Multi-Recycled Thorium Fuel - 12394

F. Franceschini¹, C. Fiorina^{2,4}, M. Huang³, B. Petrovic³, M. Wenner¹, J. Krepel⁴

¹ Westinghouse Electric Company, Cranberry Township, PA - USA

² Polytechnic of Milano, Milan – Italy

³ Georgia Technology University, Atlanta, GA - USA

⁴ Paul Sherrer Institute - Switzerland

ABSTRACT

As described in companion papers, Westinghouse is proposing the implementation of a thorium based fuel cycle to burn the transuranic (TRU) contained in the used nuclear fuel. The potential of thorium as a TRU burner is described in another paper presented at this conference. This paper analyzes the long-term impact of thorium on the frontend and backend of the fuel cycle. This is accomplished by an assessment of the isotopic make-up of Th in a closed cycle and its impact on representative metrics, such as radiotoxicity, decay heat and gamma heat.

The behavior in both thermal and fast neutron energy ranges has been investigated. Irradiation in a Th fuel PWR has been assumed as representative of the thermal range, while a Th fuel fast reactor (FR) has been employed to characterize the behavior in the high-energy range. A comparison with a U-fuel closed-cycle FR has been undertaken in an attempt of a more comprehensive evaluation of each cycle's long-term potential.

As the Th fuel undergoes multiple cycles of irradiation, the isotopic composition of the recycled fuel changes. Minor Th isotopes are produced; U-232 and Pa-231 build up; the U vector gradually shifts towards increasing amounts of U-234, U-235 etc., eventually leading to the production of non negligible amounts of TRU isotopes, especially Pu-238. The impact of the recycled fuel isotopic makeup on the in-core behavior is mild, and for some aspects beneficial, i.e. the reactivity swing during irradiation is reduced as the fertile characteristics of the fuel increase. On the other hand, the front and the back-end of the fuel cycle are negatively affected due to the presence of Th-228 and U-232 and the build-up of higher actinides (Pu-238 etc.). The presence of U-232 can also be seen as advantageous as it represents an obstacle to potential proliferators.

Notwithstanding the increase in the short-term radiotoxicity and decay heat in the multi-recycled fuel, the Th closed cycle has some potentially substantial advantages compared to the U cycle, such as the smaller actinide radiotoxicity and decay heat for up to 25,000 years after irradiation.

In order for these benefits to materialize, the capability to reprocess and remotely manufacture industrial amounts of recycled fuel appears to be the key,

INTRODUCTION

A comprehensive approach to used nuclear fuel (UNF) and high level waste (HLW) management optimization has been proposed by Westinghouse and presented in Ref. 1. In summary, this approach proposes the development of a nuclear system from the “back to the front” of the fuel cycle, i.e. first setting the appropriate criteria for the wastes and subsequently developing a viable system with the best potential to conform to the waste specifications. The waste criterion proposed, ultimately aimed at improving public acceptance of nuclear energy, is a waste package with radiotoxicity below the U ore after 300 years of post-irradiation isolation. To achieve the 300-year radiotoxicity objective, the legacy transuranics (TRU) contained in the UNF need to be burned while keeping the process losses at a minimum. Because of its potential for high transmutation rate, Th is the carrier of choice proposed in our approach to burn the legacy TRU, as discussed in Ref. 2. However, it is crucial to ensure that while burning the current legacy TRU, Th does not conduce to a new one. For this reason, the Th long-term potential in a closed cycle has been analyzed and compared against the counterpart U closed cycle.

The assessment of Th performance in a closed cycle has been accomplished examining the isotopic make-up of multi-recycled Th fuel and its impact on representative metrics, such as radiotoxicity, decay heat and gamma heat. The behavior in both thermal and fast neutron energy ranges has been investigated. Irradiation in a Th fuel PWR has been assumed as representative of the thermal range, while a Th fuel fast reactor (FR) has been employed to characterize the behavior in the high-energy range. A comparison with a U fuel closed-cycle FR has been undertaken to show the relative merits and shortcomings. State-of-the-art reactor physics tools have been employed to carry out the neutronic simulations, with in-house methodologies developed to streamline the simulation of in-reactor and out-of-reactor fuel cycle operations.

The paper is structured as follows: the methods and framework for the analysis are described, the main core performance indicators of the designs chosen are reviewed, the isotopic characterization of the recycled fuel in a closed Th and U cycle is discussed, the radiotoxicity, decay heat and gamma heat for the various options is evaluated and finally conclusions are drawn.

METHODS

The reactors employed to perform the analysis are listed below, with their main features summarized in Table 1. The notation “U-Pu” is used to indicate a mixture of natural U as the bulk fertile and in-bred Pu as the main fissile. The notation “Th-U” is used to indicate a mixture of natural Th and U in-bred from Th.

- Fast spectrum: lead-cooled fast reactor ELSY
- Thermal spectrum: PWR with standard 17x17 fuel assembly

ELSY is a lead-cooled fast reactor (LFR) presently developed in the LEADER (LEAD European Reactor) project of the seventh framework program (2007-2011) (Ref. 3 and 4). The reference

ELSY design features a U-Pu oxide core. In addition, a Th-U core using nitride fuel has been developed to assess the behavior of thorium in the fast spectrum. Nitride enriched in N-15 has been proposed to reduce the generation of radiotoxic C-14 from (n,p) reactions in N-14, thereby also improving neutron economy. Both the Th-U and U-Pu cores of ELSY have been designed to achieve a zero net breeding gain (“iso-breeders”).

The PWR features a 4-loop 193-assembly core and standard 17x17 fuel assembly design with homogeneous loading pattern of Th-U oxide pins. A 3-batch core and 18-month refueling intervals with a ~0.9 capacity factor and ~4 Effective Full Power Years (EFPY) of irradiation at batch discharge have been adopted. While the potential for breeding exist in a thermal spectrum for Th, the standard PWR design used in this study has a breeding ratio of < 1 and therefore requires an external fissile supply to restore the depleted fissile inventory of the fuel being recycled, as discussed next.

Table 1: Core Main Parameters

	PWR (Thorium)	LFR (Thorium)	LFR (Uranium)
Electric power (MWe)	1,000	600	600
Thermal power (MWt)	3,060	1,500	1,500
Fuel type	Th-UO ₂	Th-UN	U-PuO ₂
Core Cycle length (EFPY)*	~1.3	2	2
Number of batches**	3	3	3
Discharge burnup (MWd/kgHM)	55	50	73
Refueling time (days)	30	30	30
Reference Recycle Strategy	All Actinides	All Actinides	All Actinides
Cooling time (yr)	5	5	5
Batch In-core Cycle length (yr)	4.5	6	6
Breeding Ratio	~0.5	1.0	1.0
Make-up fertile	Natural Th	Natural Th	Natural U
Top-up fissile	U-233	Not needed	Not needed

*EFPY: Effective Full Power Years ** 1-batch approximation was assumed for the inventory calculations

The fuel management strategy employed is depicted in Figure 1. Both reactors operate on a closed fuel cycle: after discharge from the core, a fuel batch undergoes 5-year cooling and reprocessing, with separation of actinides from the fission products (FPs). The FPs are disposed together with 0.1% of the actinides inventory, which have been assumed as representative of the process losses. The remaining 99.9% actinides recovered are recycled and manufactured into a new fuel batch.

Since the Th-U and U-Pu cores of ELSY achieve a zero net breeding gain, only natural Th and natural U respectively need to be added to the recycled stream to preserve the fertile fuel inventory of the new fuel batch. On the other hand, since the Th-U PWR has a breeding ratio < 1, fertile (natural Th) as well as fissile (U-233) materials need to be added to the recycled stream to restore the fuel inventory and fissile quality at the beginning of the previous cycle. About 50% of the U-233 in the fresh fuel comes from reprocessing of the previous batch while the rest needs to be provided externally to the PWR fuel cycle. The external U-233 top-up is an expedient adopted in lieu of developing a thermal breeder design, which is beyond the scope of this analysis. The results obtained are adequate for a preliminary comparison of Th-U recycled fuel in a thermal vs. a fast spectrum. Since a U-Pu thermal breeder is precluded by neutron physics considerations, this option has not been examined.

The reactor physics tool employed for the PWR simulations is the SCALE 6 package (Ref. 5), with an algorithm developed to streamline in-core core calculations and out-of-core mass flows. The fast reactor ERANOS 2.2 suite with the EQL3D procedure has been employed for in-core and out-of-core calculations for the LFR (Ref. 6 and 7)

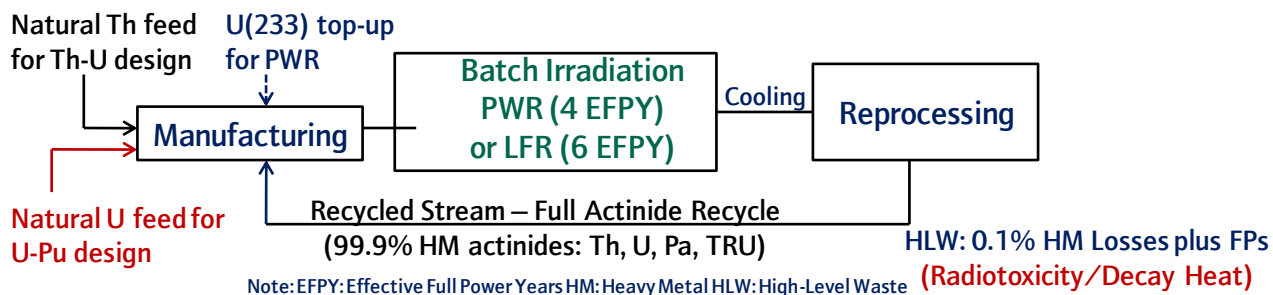


Figure 1 Fuel management strategy assumed for two reactors

ISOTOPIC CHARACTERIZATION OF Th-BASED PWR VS. LFR

The seed fissile for the Th-U start-up cores has been assumed to be 100% U-233 in U. The U-Pu LFR start-up core has a seed of Pu at the typical composition of LWR reprocessed UNF. As the fuel is being irradiated and recycled, the isotopic composition will reach an asymptotic equilibrium which will depend from the feed, i.e. Th or U, regardless of the initial core. Since the feed for the Th-U PWR contains U-233, in addition to Th, they will both play a role in the equilibrium fuel composition.

Table 2 shows that the lead-cooled fast reactor has a lower specific power but longer batch irradiation time, plus it features higher energy conversion efficiency than the PWR. The resulting heavy-metal (HM) discharged per energy generated is 20.1 MT/kWe-yr in the PWR vs. 17.8 and 12.4 MT/kWe-yr in the Th-U and U-Pu LFR, respectively. The higher discharge burnup for the U-Pu vs. Th-U LFR is a consequence of the better neutron economy and fuel utilization of the U cycle in the fast energy range. Due to the larger fission cross-section in a thermal spectrum, the PWR requires less fissile than the LFR, ~4% vs. 10-12% of the fuel HM inventory respectively. The average fissile content per energy generated over 50 simulated recycles amounts to ~840

kg/GWe-yr vs. 1,730 kg/GWe-yr for respectively the PWR and LFR. The average fissile Pu for the U-Pu LFR is 1,280 kg/GWe-yr.

Table 2: Fuel Batch Main Parameters

Parameter	PWR (Thorium)	LFR (Thorium)	LFR (Uranium)
Specific power (Wt/gHM)	38.15	23.47	33.55
Batch cycle length (in-core, EFPY)	4.0	6.0	6.0
Energy per Batch (GWe-yr)	1.33	1.20	1.20
Batch HM content (kg)	26,740	21,320	14,914
HM Content (kg/GWe-yr)	20,105	17,750	12,417
Fissile at start-up (% of HM)	3.95	11.59	10.33
Fissile at equilibrium (% of HM)	4.22	9.56	10.44
Average Fissile Content (kg/GWe-yr)	840	1,730	1,280

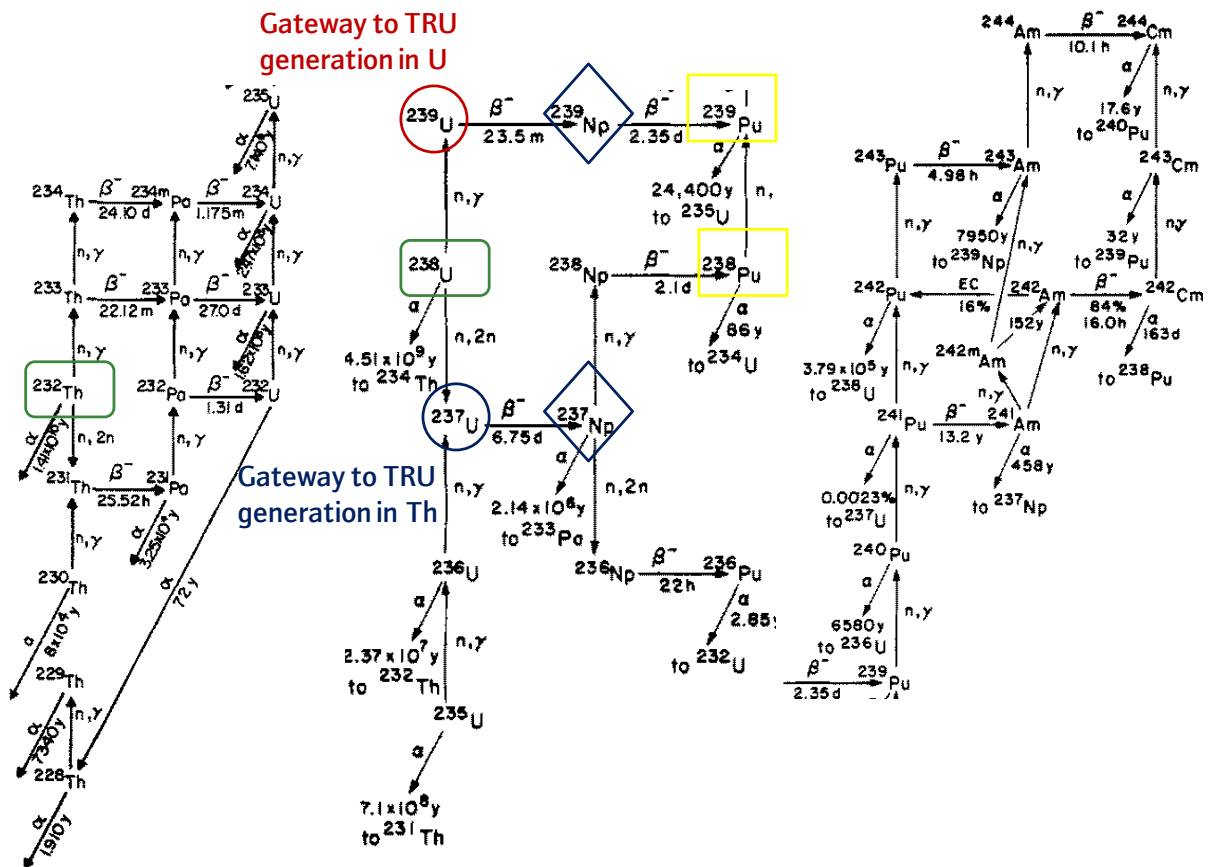


Figure 2 Neutron transmutation chain from Th-228 to Cm-244 [adapted from Ref. 8]

The transmutation chain for the relevant isotopes involved is depicted in Figure 2, adapted from Ref. 8. As Th-U fuel is being irradiated and recycled, a concatenation of neutron captures and decays eventually leads to the generation of small but appreciable amounts of Np-237, Pu-238 and higher actinides. In the U cycle, the direct pathway to the generation of Pu from neutron absorptions in U-238 leads to larger amounts of higher actinides than in the Th cycle. Beside the amounts and relative position on the transmutation chain of the respective feeds, the neutron spectrum plays a key role in the generation rate and isotopic makeup of each cycle and reactor.

As shown in Figure 3, the harder spectrum of the LFR leads to smaller sigma fission-to-capture ratios, especially for non fissile isotopes, up to 100 times for certain isotopes (Np-237, Pu-240, Pu-242, etc.).

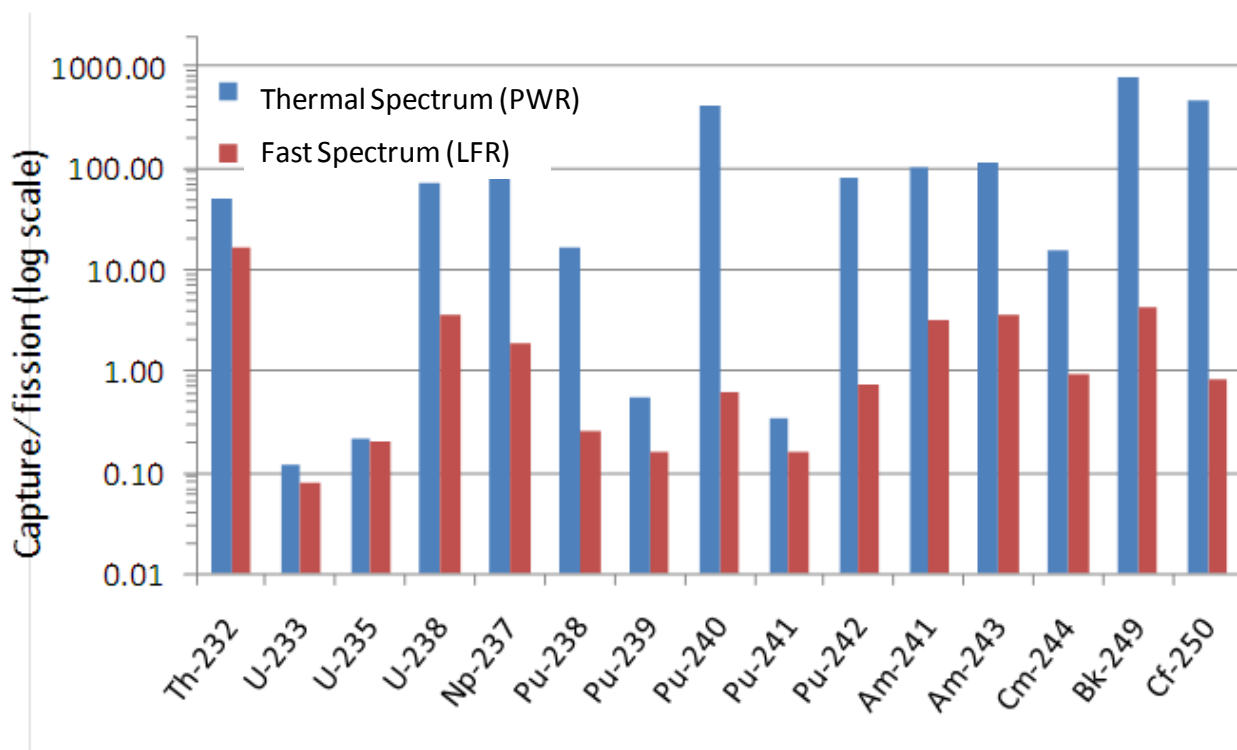


Figure 3 Capture/Fission cross-section for PWR and LFR

As a result of the harder spectrum, the generation of higher actinides is inhibited in the Th-LFR, resulting into a slower buildup compared to the Th-PWR. This phenomenon is illustrated in Figure 4 and Figure 5, which show the actinide buildup for the Th-PWR (leftmost chart), Th-LFR (mid chart) as well as the U-LFR (rightmost chart). Note that the kg amounts on the “y” axis are

normalized by the energy per batch (i.e. 1.33 and 1.20 GWe-yr respectively for the PWR and LFR), while the energy on the “x” axis is the cumulative energy including the recycles. As Figure 5 shows, all the actinides tracked have practically reached equilibrium by the end of the irradiation period simulated in the Th PWR, unlike in the Th LFR where TRU isotopes are still evolving even after ~100 GWe-yr, corresponding to 168 Effective Full Power Years (EFPY) for the LFR. Therefore true equilibrium has not yet been established for the Th LFR.

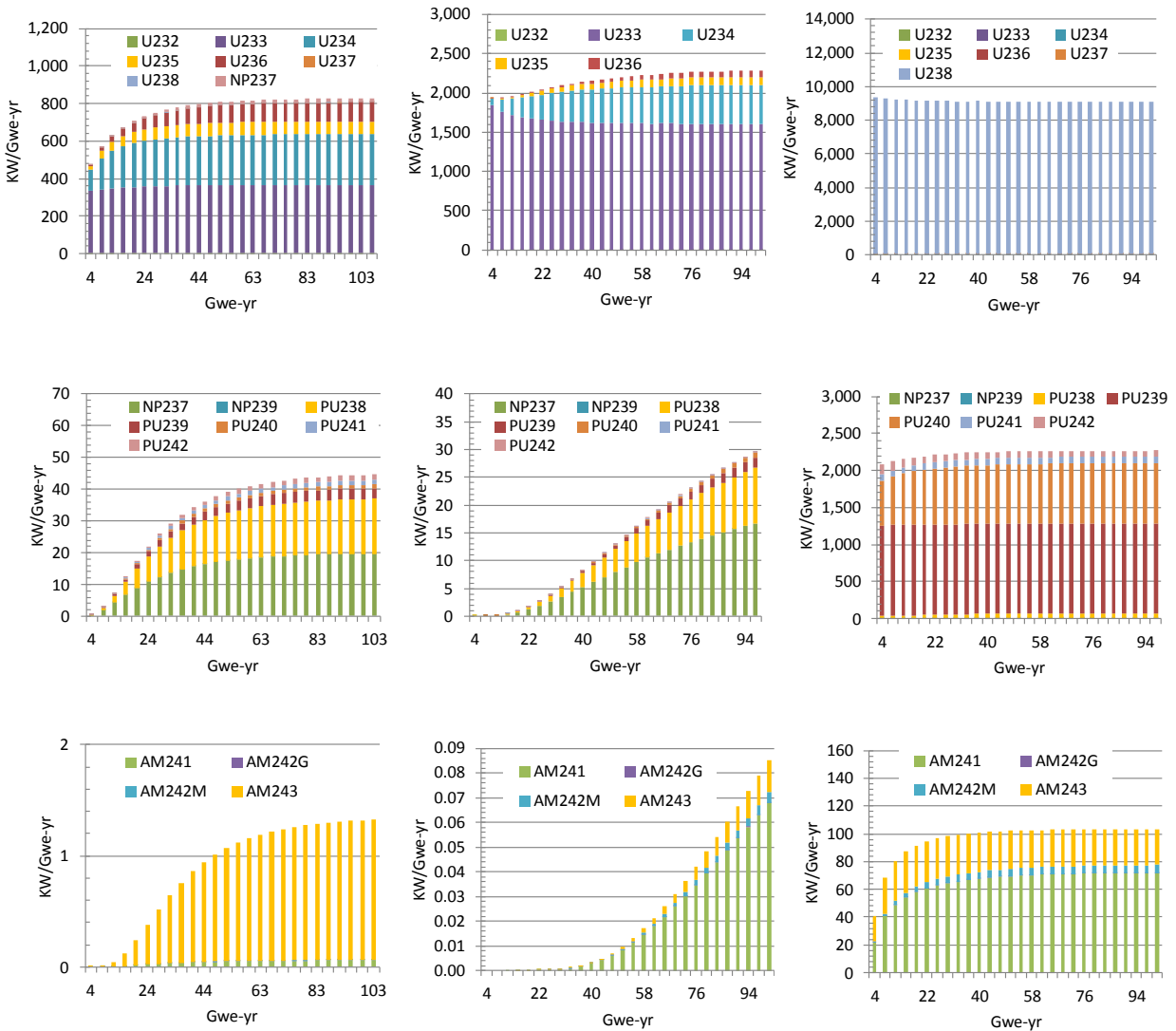


Figure 4 Isotopic Content of the Th-PWR (leftmost charts), Th-LFR (mid charts) and U-LFR (rightmost charts) (1 of 2)

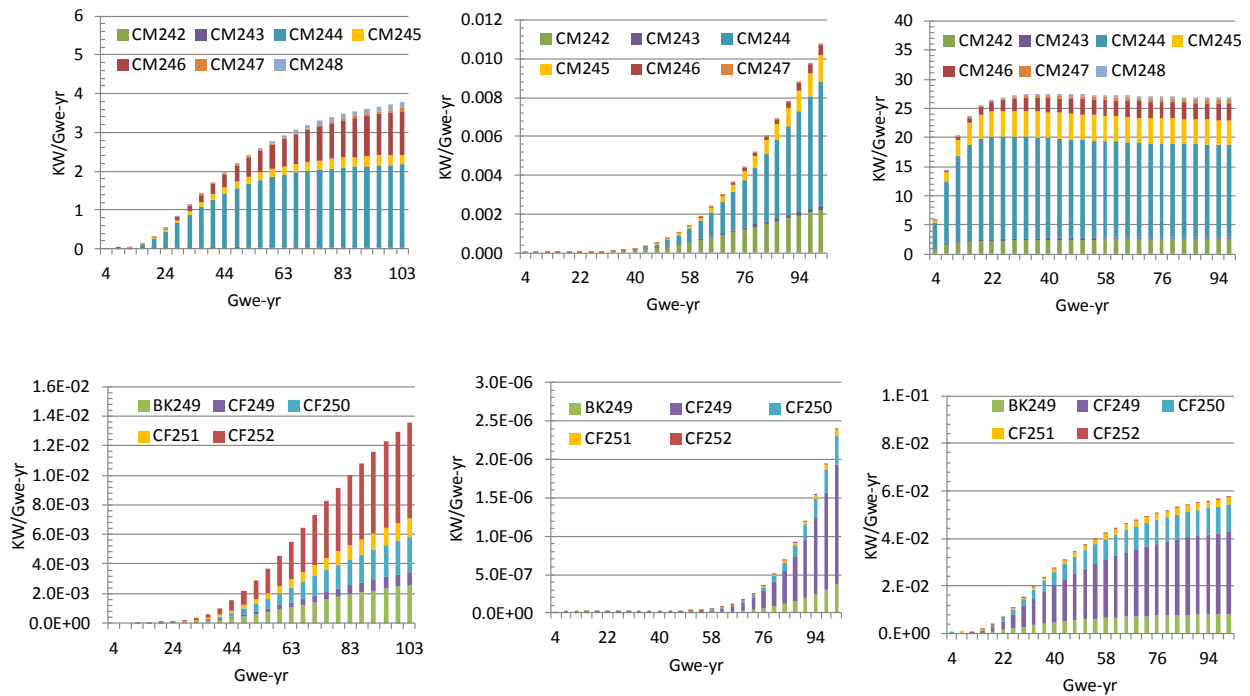


Figure 5 Isotopic Content of the Th-PWR (leftmost charts), Th-LFR (mid charts) and U-LFR (rightmost charts) (2 of 2)

Table 3: Actinides in 1-yr cooled discharged PWR and LFR fuel after a cumulative irradiation of 100 GWe-yr. Amounts are in Kg/GWe-yr, with GWe-yr energy of each individual cycle, not the cumulative energy.

Amount in kg	PWR (Thorium)	LFR (Thorium)	LFR (Uranium)
Th	18,114	14,519	-
Pa	2.1	5.0	-
U	831	2,307	9,091
Np	20.5	17.1	14.3
Pu	23.2	13.4	2,254
Am	1.8	0.09	103.4
Cm	4.8	0.01	26.8
Cf	6.8E-03	2.0E-06	8.1E-03

A summary comparison for the various elements and isotopes after 100 GWe-yr of cumulative irradiation is given in Table 3 and Figure 6 for the various isotopes.

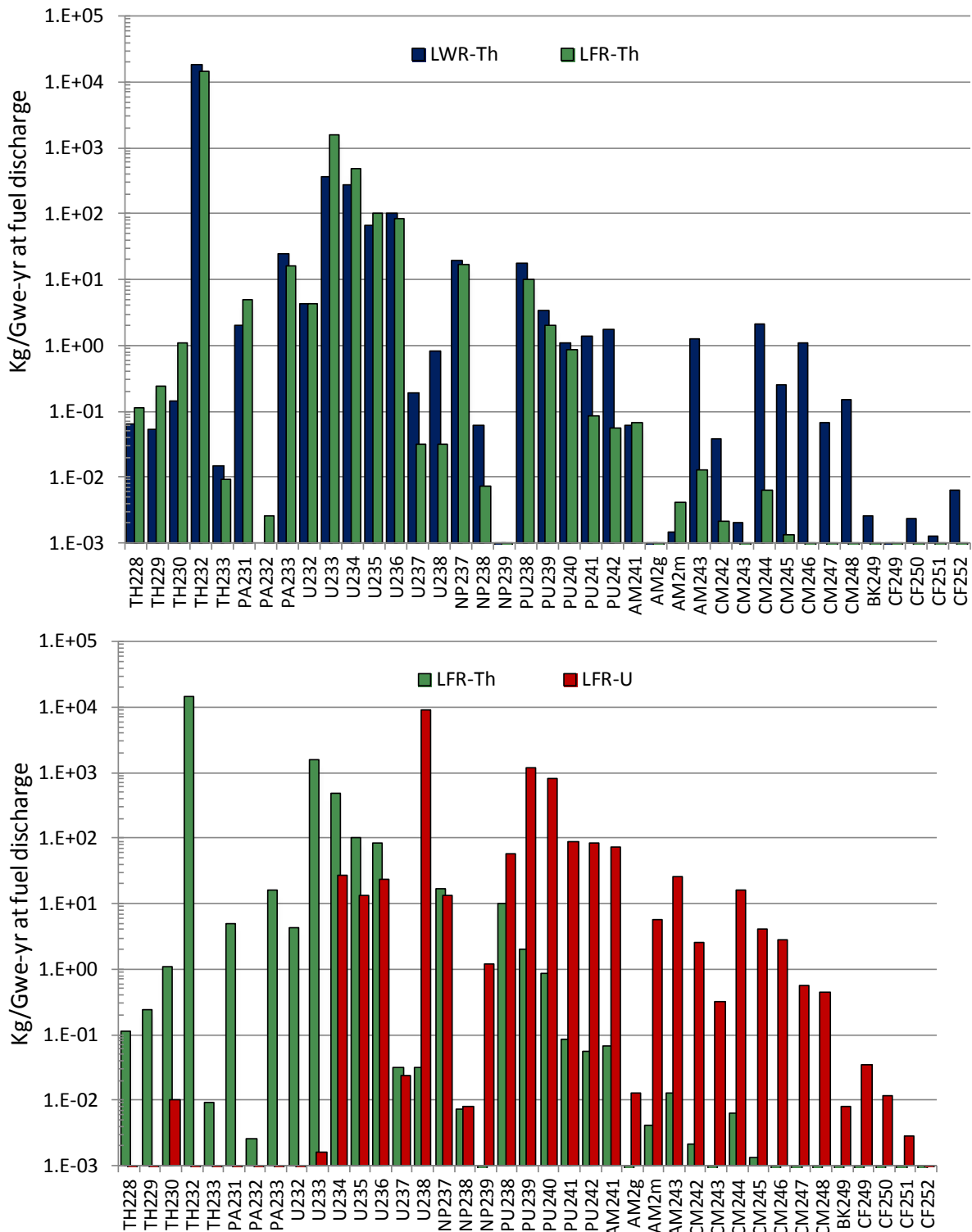


Figure 6 Isotopic content (kg/GWe-yr) of discharged fuel from the Th-PWR and Th-LFR (top chart) and U-LFR (bottom chart) after a cumulated irradiation of 100 GWe-yr

In spite of the larger fissile content, the harder spectrum leads to lower Np and Pu and much lower higher actinides, for the Th-LFR vs. the PWR. The Th-LFR features a larger Pa content, primarily Pa-231 in the 1-yr cooled fuel, due to larger (n,2n) reaction rate in Th-232. As a result of the pathway for direct transmutation of U-238 into Pu-239, the U-LFR leads to much larger concentrations of Pu, Am and Cm relative to the Th cycle, fast and thermal. The amount of Cf is similar to the Th-PWR but much higher than the Th-LFR. The amount of Np featured in the U-LFR is smaller.

The impact of the different isotopic composition of Th-based PWR and LFR fuel will be reviewed in the following sections, focusing on selected fuel cycle backend and frontend metrics.

RADIOTOXICITY OF Th-BASED PWR AND LFR ACTINIDE INVENTORY

Radiotoxicity calculations were performed using the ORIGEN module of the SCALE 6 package (Ref. 5) based on the actinide isotopic inventory at fuel batch discharge. Given that all 3 cycles are closed cycles, the main cycle to cycle contribution to the HLW derives from the actinide process losses (reprocessing, fuel manufacturing etc.) and the fission products. In addition, the fuel inventory at reactor decommissioning, if not employed in another reactor, needs to be disposed, either directly or after a final burn, for instance in a sub-critical system if available. Since the focus is on intermediate to long-term radiotoxicity, 300 years after discharge and beyond, the fission products have not been included in the analysis (in addition, they would have a similar impact for all cases).

The process losses have only been assumed for now due to lack of actual data and the many uncertainties associated to a potential deployment on an industrial scale. Same process losses, 0.1% of the actinide inventory, have been tentatively used for the reactor systems simulated, as shown in Figure 1. Assuming same process losses for the systems, and same recovery ratio over the isotopic spectrum, allows a consistent comparison of the respective potential trying to avoid undue penalization of one option vs. the other. This assumption can be revisited once more data on the performance of the reprocessing and fuel manufacturing route devised can be ascertained.

The radiotoxicity from the Th-U cycle 0.1% postulated actinide waste is shown in Figure 7. In particular, Figure 7 shows the ingested radiotoxicity index, as m³ of water, of the Th-U PWR and LFR waste per GWe-yr normalized by the radiotoxicity of an “equivalent” amount of natural U in secular equilibrium with its decay products. This equivalent natural U corresponds to that required to fuel a typical PWR open cycle generating the same amount of electricity of the Th-U PWR and LFR. The ensuing inventories used for the radiotoxicity calculations amount respectively to: ~19 and 17 kg actinides losses for respectively the Th-U PWR and LFR, and 215 MT of “equivalent” natural U in the ore (with an ingested radiotoxicity index of 10.5 billions of cubic meters of water).

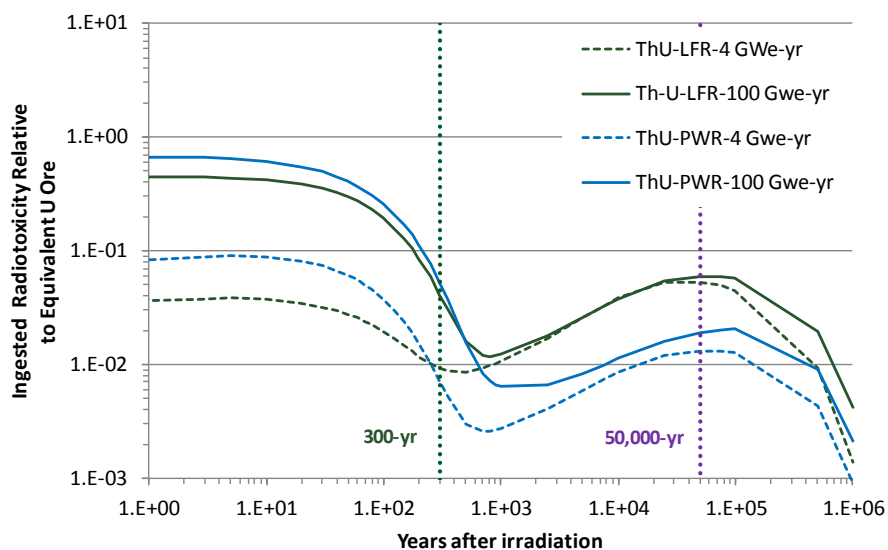


Figure 7 Ingested Radiotoxicity 0.1% HM losses from Th-U PWR and LFR fuels

Figure 7 reveals the typical radiotoxicity trend of Th-U fuels: flat in the first 50 years after irradiation, rapidly decreasing afterwards and reaching a minimum at ~ 1,000 years, slowly increasing to a maximum in the 25,000-100,000 year range and decreasing afterwards. The radiotoxicity in the initial years after discharge is driven primarily by U-232, which quickly builds up during irradiation of Th fuel, and Pu-238, which takes more irradiation cycles to build up. The Pu-238 buildup is responsible for most of the increase in radiotoxicity from 4 GWe-yr vs. 100 GWe-yr of irradiation. As the U-232 and Pu-238 decay, with a half-life of ~70 and ~88 years, the radiotoxicity decreases and U-233, with a half-life of ~160,000 years, becomes the dominating contributor to radiotoxicity. As the Th-229 activity builds up, from U-233 decay, and Th-230 builds up from U-234 decay, with a half-life of ~250,000 years, the radiotoxicity reaches a maximum and then finally decreases. Note that as a result of the U-233 predominance, the impact of the cumulated irradiation on the long-term radiotoxicity is marginal, as the overall amount of U-233 will only change slightly in the recycled fuel.

Comparing the Th-U waste in the fast vs. thermal spectra reveals an LFR actinide waste with a lower radiotoxic content in the 0-300 year interval after irradiation, while the opposite is true at longer times. The lower radiotoxicity in the 0-300 yr range is due to the reduced LFR U-232 inventory (in the low range of cumulated irradiation time) and lower Pu-238 inventory (at 100 GWe-yr of cumulated irradiation). The larger LFR radiotoxicity at longer times after irradiation is a consequence of its larger U-233 and U-234 inventory. Notably, the HLW radiotoxicity of 0.1% actinide inventory from the Th-U cycle keeps below the equivalent U ore at all times analyzed.

The radiotoxicity of the Th vs. U LFR actinide waste is depicted in Figure 8, showing larger radiotoxicity for the U LFR in the 0-25,000 year range following its larger amount of TRU, Pu-238, Pu-239, Pu-240, Pu-241 and Am-241 primarily. The reduced radiotoxicity at higher decay times is driven by Pu-239, which has lower specific radiotoxicity than U-233. Finally, a comparison of the isotope-wise radiotoxicity index at 300-year after decay for the three fuels considered is given in Figure 9. A cumulative irradiation time of 100 GWe-yr has been assumed.

The larger content of Pu and Am typical of the U closed cycle is accounting for its larger 300-year radiotoxicity.

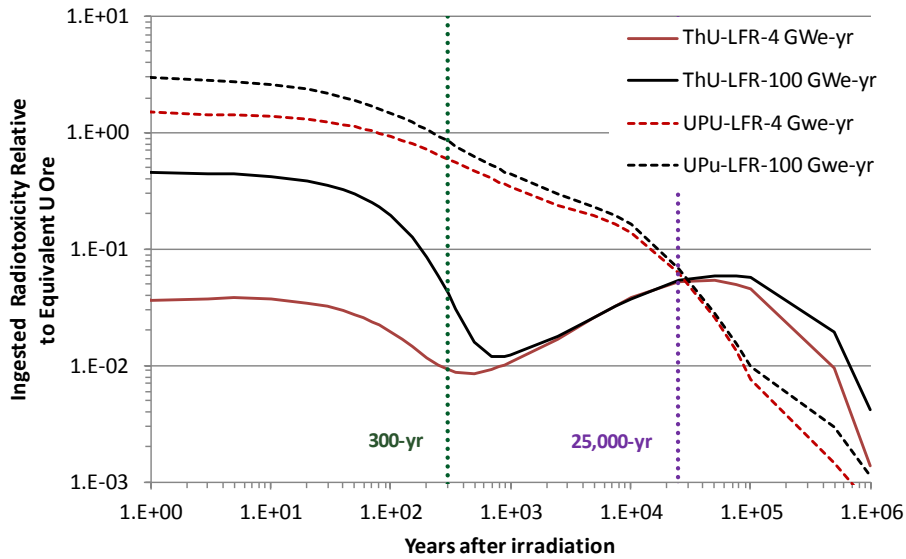


Figure 8 Ingested Radiotoxicity 0.1% HM losses from Th-U and U-Pu LFR fuels

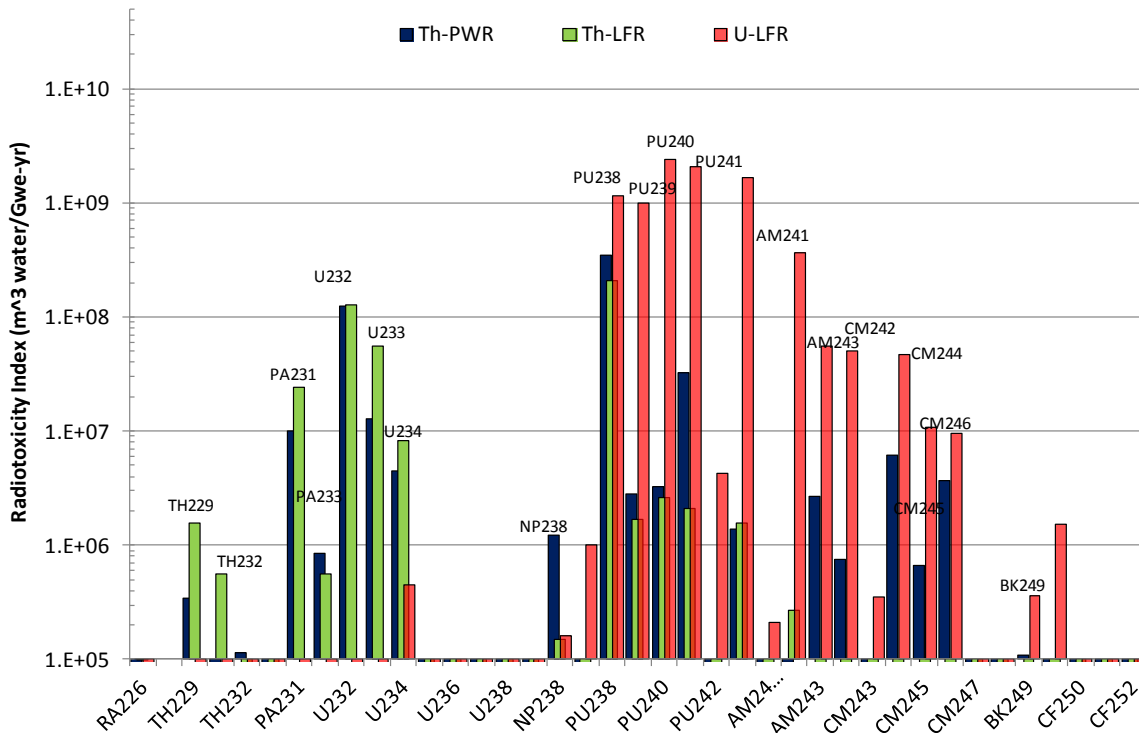


Figure 9 Ingested radiotoxicity index at 300-yr after discharge for of 0.1% HM losses of PWR and LFR fuel with a cumulated irradiation of 100 GWe-yr.

DECAY HEAT OF ACTINIDE WASTE FROM Th vs. U LFR

The decay heat of 0.1% actinide waste from the Th-U and U-Pu LFR discharged fuel is shown in Figure 10. The behavior of the Th-U PWR actinide waste is not analyzed further as similar to the Th-U LFR. Note in Figure 10 that the decay heat of the actinide waste is normalized by the energy generated. Alternatively, the MT of actinide disposed could be used for the normalization but the impact of the different amounts of HM required in the two reactors to obtain the same energy would be lost. Note also that similarly to previous cases, the decay heat of the fission products is not shown as it will be predominant in the short time range (< ~300 years) and would be similar for the two cases considered.

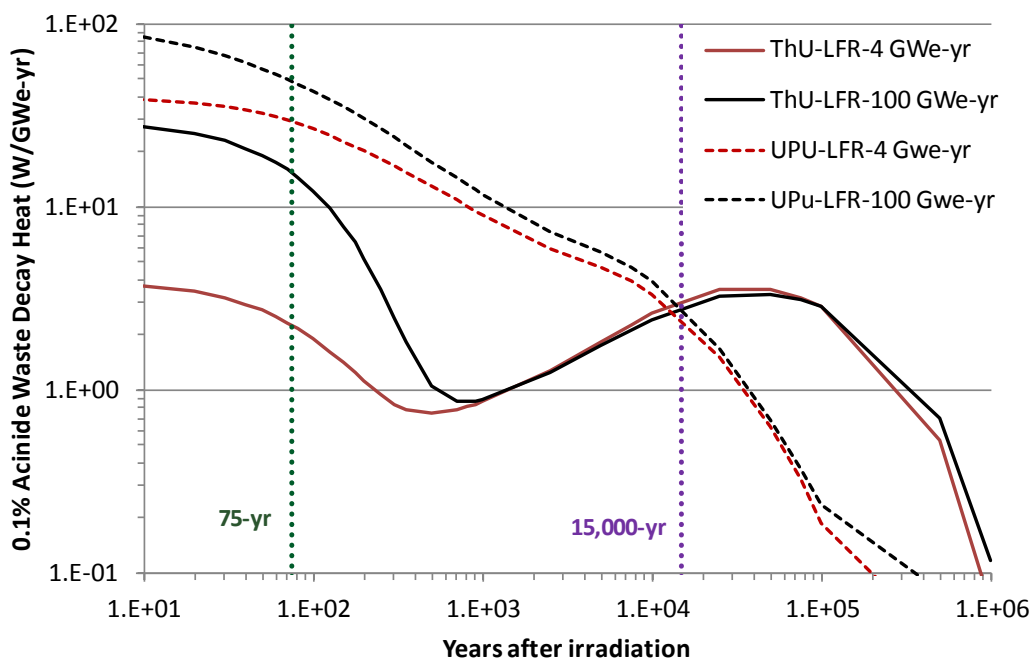


Figure 10 Decay heat from 0.1% HM losses of Th-U and U-Pu LFR fuel (W/GWe-yr)

The behavior of the decay heat of the hypothetical actinide waste for the two cycles analyzed is similar to that observed for the radiotoxicity plots. Th-U maintains its characteristic sharp decrease during the first tens of years after discharge, reaches a minimum at ~ 1,000 years, once the U-232 and Pu-238 have decayed, and then slowly increases towards a new maximum at ~25,000 years, due to the raising activity from buildup of U-233's and, at longer decay time, U-234's decay products. The decay heat of the U-Pu LFR's actinide waste is dominated by TRU isotopes, similarly to what already described for the radiotoxicity.

The potential reduction of the actinide decay heat fostered by Th in the time range between 100-10,000 years could be beneficial to the thermal performance of the disposal site and deserves further attention.

GAMMA HEAT OF Th vs. U FUEL AT MANUFACTURING

Beside the reactor performance and potential improvements in the back-end of the fuel cycle, front-end metrics should be looked as well for a comprehensive evaluation of the potential of any fuel cycle. It is generally acknowledged that thorium can claim better resource availability and more environmentally friendly mining than U. The fuel utilization and amount of raw material to be made available for fabrication will be much smaller in the closed cycles analyzed compared to the once-through PWR. For the specific LFR design chosen, U features a 20% higher discharge BU and accordingly better fuel utilization than Th, thanks to the better neutron economy in the fast neutron energy range. The capacity and cost of the fuel manufacturing facility would benefit accordingly. A key economic, if not technological, factor when comparing fuel cycles is the need for shielding and automation of the fuel manufacturing line as a result of the radioactivity content of the recycled fuel. The gamma heat at fuel manufacturing is selected here as the relevant metric for indicating such need.

The gamma heat of the Th-U recycled fuel is dominated by hard gamma energy emitters in the U-232, and thus Th-228, decay chain: Tl-208, with 2.6 MeV gamma, and, to a lesser extent, Pb-212 (0.4 MeV gamma) and Bi-212 (1.8 MeV gamma) (see Ref. 8 for a background discussion on this topic). Once the fuel is reprocessed, the decay products will be disposed but they will newly buildup from the amounts of Th-228 and U-232 in the recycled fuel going to the manufacturing line. The recycled Th-228, having a higher activity and shorter half-life than U-232 (~2 years vs. 70 years), is responsible for the short-time increase in gamma-heat after the separation. U-232 is responsible for the long-time gamma-heat component.

Due to the above considerations, two options have been analyzed for Th-U recycled fuel manufacturing: 1) keeping Th with the rest of the recycled fuel and adding natural Th as make-up fertile; 2) partitioning Th out at the reprocessing and manufacturing new fuel with the remaining actinides and fresh, natural Th. The partitioned Th would be assigned to temporary storage, with ~20 years of decay before being re-employed as fertile make-up fuel. For the U-Pu LFR, all recovered actinides are recycled and together with natural U make-up are assumed to be manufactured into a new fuel batch.

The gamma heat resulting from the various options is shown in Figure 11. In particular the W/kgHM as a function of the time after separation, with a 5-year cooling time from fuel discharge to reprocessing, is shown.

For the Th-U fuel, the gamma heat from Option 1) shows a quick raise in the gamma activity, controlled by the decay of 3.5-day half-life Ra-224. This steep increase in gamma activity brings the gamma heat in the recycled Th-U fuel to comparable levels of the U-Pu fuel already after 4 days after separation, then reaching a maximum value ~ 1 order of magnitude higher in a few weeks. Option 2) delays the raise in the gamma activity due to the time needed to restore Th-228 from U-232's decay and buildup of the associated gamma emitters. The gamma activity for Option 2) keeps below that of U-Pu for up to 6 months after the separation, reaching a maximum after ~10 years and then decreasing.

It should be kept in mind the different energy distribution, and therefore shielding requirements, for the gamma rays emitted for the two fuels: larger than 1 MeV for Th-U fuel where up to 80% of the total gamma activity is from Tl-208 decay, and below 100 KeV for U-Pu where 80% of the

gamma activity is from Am-241 decay and the remaining 20% is from Pu-238, yielding discrete gamma rays in the tens of KeV range for thousands of years after the separation.

The buildup of gamma activity in the Th-U recycled fuel, while possibly delayed by assigning irradiated recovered Th to temporary storage upon recycling, is certainly greatly penalizing to handling operations and shipments, and will require shielding and remote operation of part, or all, of the manufacturing line. Qualitatively similar considerations apply to recycled fuel in a Th-U thermal spectrum, worsened by the higher U-232 content in recycled U.

The shielding and remote manufacturing requirements for the U-Pu cycle, while reduced compared to Th-U, deserve attention and further evaluations. In addition the possible issues deriving from spontaneous fission neutron emission from higher actinides in the U-Pu recycled fuel should also be quantified in future analysis.

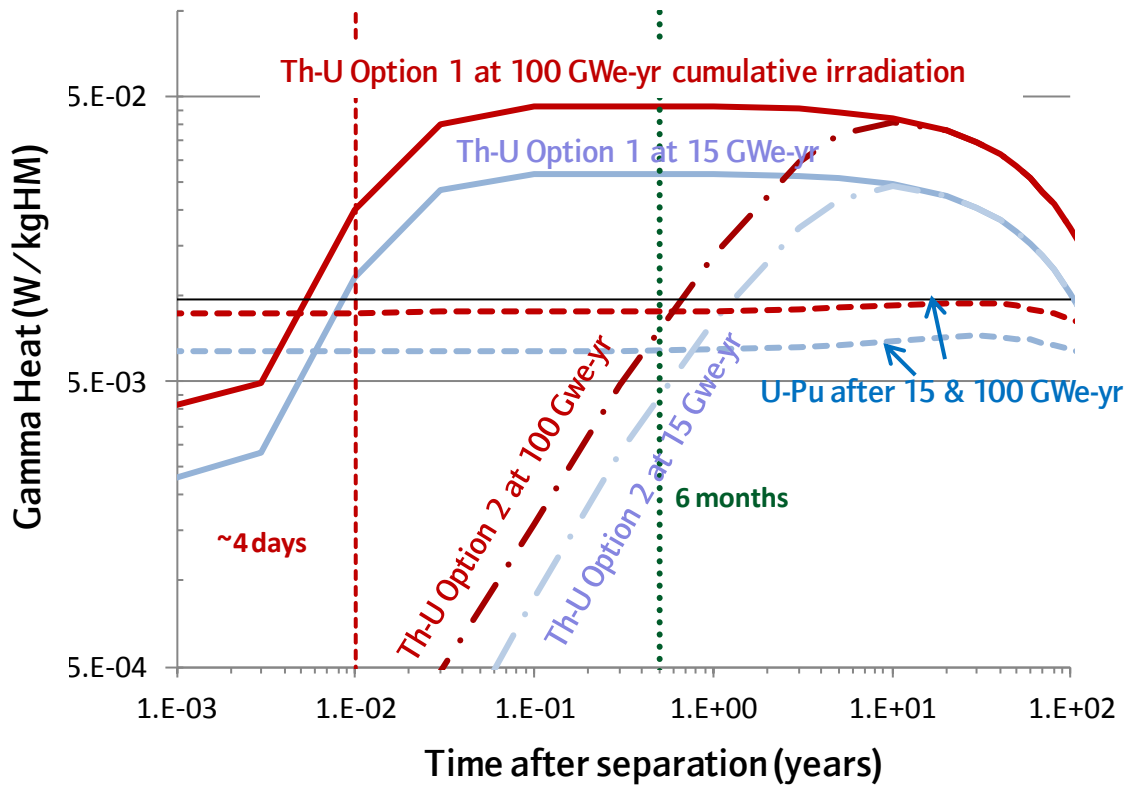


Figure 11 Gamma heat of Th-U and U-Pu LFR fuel with various fuel manufacturing options and cumulative irradiation times for the recycled fuel

CONCLUSIONS

Westinghouse is proposing the implementation of a thorium based fuel cycle to burn the TRU contained in the current UNF. The general approach and the potential of thorium as TRU burner is described in other papers presented at this conference. The focus of this paper is to analyze the long-term potential of thorium, once the legacy TRU has been exhausted and the thorium reactor system will become self-sufficient. Therefore, a comparison of Th closed cycle, in fast and thermal neutron energy ranges, vs. U closed cycle, in the fast energy range, has been undertaken. The results presented focus on selected backend and frontend metrics: isotopic actinide composition and potential implications on ingested radiotoxicity, decay heat and gamma heat.

The evaluation confirms potential substantial improvements in the backend of the fuel cycle by transitioning to a thorium closed cycle. These benefits are the result of a much lower TRU content, in particular Pu-241, Am-241 and Pu-240, characterizing the Th vs. U actinide inventories, and the ensuing process waste to be disposed. On the other hand, the larger gamma activity of Th recycled fuel, consisting predominantly of hard gammas from U-232's decay products, is a significant challenge for fuel handling, transportation and manufacturing but can be claimed as beneficial for the proliferation resistance of the fuel.

It is worth remembering that in our perspective the Th closed cycle and the U closed cycle will follow a transmutation phase which will likely take place over several decades and dictate the technologies required. These will likely include remote fuel manufacturing, regardless of the specific system adopted for the transmutation, which could then be inherited for the ensuing closed cycles.

Finally, specific data related to the fuel manufacturing and separation technologies and their performance in the prospected industrial scale deployment, are key for further quantification of the potential merits of the options explored. Further studies in this direction should be warranted before making definitive conclusion.

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