"Radiotoxicity Index": An Inappropriate Discriminator for Advanced Fuel Cycle Technology Selection - 12276

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ABSTRACT

A radiotoxicity index (RI) is often used as a figure of merit for evaluating for evaluating the attractiveness of employing an advanced fuel cycle (i.e., a fuel cycle that uses some combination of separations and other reactor technologies, such as fast reactors), rather than continued use of the current "once-through" fuel cycle. The RI is calculated by multiplying the amount of every radionuclide found in a waste form for some unit amount of waste times the drinking water dose conversion factor, DCF, for each radionuclide, then summing these together. Some argue that if the RI for an advanced fuel cycle is lower than the RI for a once-through fuel cycle, then implementation of the particular advanced fuel cycle has merit because it reduces the radiotoxicity of the waste. Use of an RI for justifying separations technologies and other components of advanced fuel cycles is not only inappropriate, but can be misleading with respect to judging benefits of advance fuel cycle options. The disposal system, through its use of multiple engineered and natural barriers to migration, eliminates most of the radionuclides contributing to the RI such that additional separations technologies will make little difference to peak dose rates. What must also be considered is the health/dose risk caused to workers and the public by the construction and operation of the separations facility itself. Thus, use of RI may lead to selection of separations technologies that may have a negligible effect on lowering the potential health risks associated with disposal, but will increase real worker and public health risks in the near term.

INTRODUCTION

Various advanced fuel cycle technologies are being studied world-wide. The majority of R&D is aimed at “closing” the nuclear fuel cycle such that some fraction of the radionuclide inventory of used fuel could be separated, recycled and/or transmuted rather than being disposed in a geological repository. Credible metrics are needed to evaluate the extent such advanced schemes will lead to a reduction of waste, and more importantly the radiological risk of such wastes, requiring disposal.

Waste reduction can be measured by comparing the “radiotoxicity index” (RI) of the spent fuel requiring disposal in a once-through scenario relative to the RI from the waste(s) that would be generated by a particular closed fuel cycle technology option. RI is calculated by multiplying the amount of every radionuclide found in a waste form for some unit amount of waste times the drinking water dose conversion factor, DCF, for each radionuclide, then summing these together.

The radiotoxicity index is a function of time as the mass of the radionuclides in the waste is a function of time.[1] A typical plot of radiotoxicity index for spent nuclear fuel and the amount of uranium ore to generate that spent fuel is shown in Figure 1.

Radiotoxicity indices from wastes generated from advanced fuel cycles that use some combination of separations and other reactor technologies, such as fast reactors, have been calculated in order to show the benefits of reducing the “hazard” of the initial used fuel. Most advanced fuel cycle technologies using the radiotoxicity index as a figure of merit involve separation of at least plutonium, and often the minor actinides. With the majority of these radionuclides removed from the waste form, the RI is lowered, and the time for the RI to be on par with the uranium ore body is shortened.

[1] The very long half-life of the radionuclides in the natural uranium ore body cause very little change in the ore body radiotoxicity index even for time periods of greater than one million years.

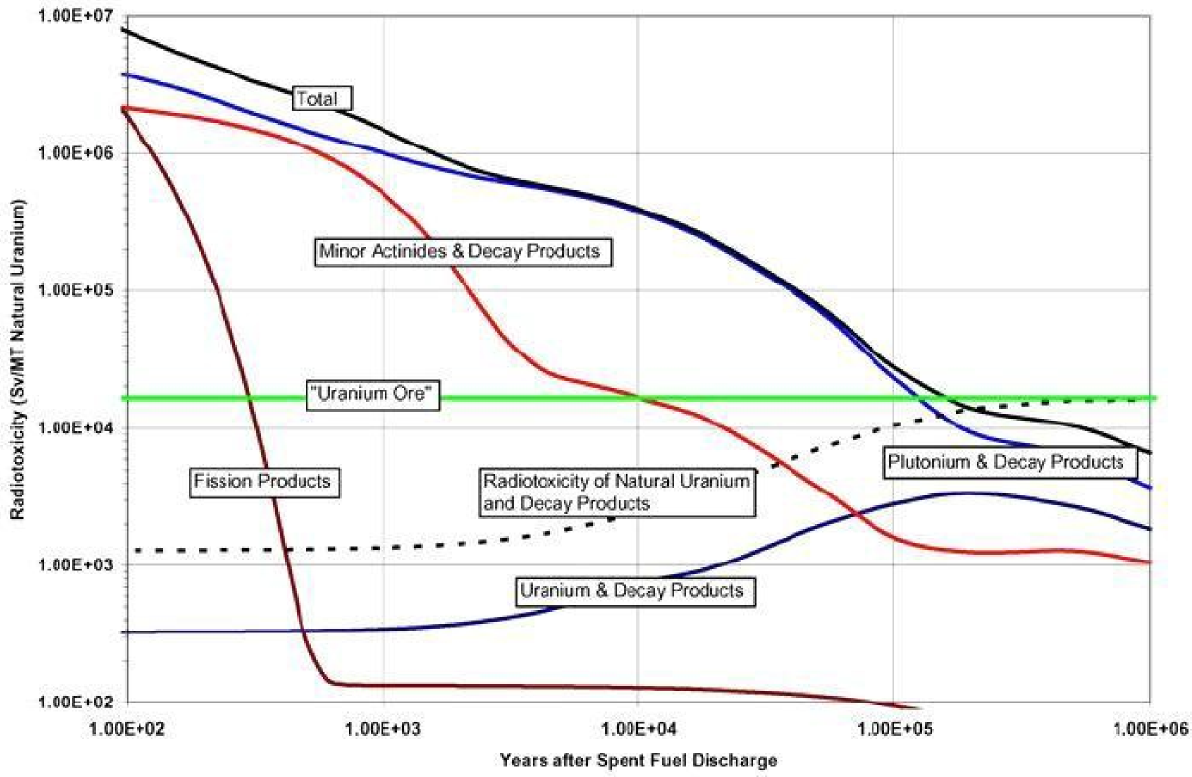

Fig. 1. Radiotoxicity of UOX spent nuclear fuel.

THE INAPPROPRIATENESS OF THE RADIOTOXICITY INDEX AS A SEPARATIONS TECHNOLOGY SELECTION DISCRIMINATOR

There are, however, at least three inappropriate aspects of using RI to demonstrate the benefits of selecting a particular separations technology.

> The RI approach does not consider the intrinsic effect the disposal system itself will have on reducing the RI of any disposed waste.
>
> What matters in terms of public health is not the RI, but consideration of the radionuclides that enter the biosphere after leaving the disposal facility and how they contribute to potential dose (risk) to a member of the public.
>
> The RI approach often does not fully include consideration of the dose/risk impacts from all of the intermediate and low level wastes (I/LLW) .that arise during the reduction of used fuel to a smaller volume of HLW with a lower RI.

To illustrate these problems with application of RI, total system performance assessments (TSPAs), universally conducted for repository disposal systems, can be utilized. Results from TSPA can be expected to differ between different disposal designs, waste forms, locations, and characteristics of the wastes. However, several decades of experience with TSPAs both in the US and internationally in multiple repository programs allow a number of generalizations to be made.

TSPAs take into account a variety of mechanisms that will lower the radiotoxicity *at a point of potential exposure* such as:

Complete waste isolation provided by the disposal canister. This allows many shorter-lived radionuclides to decay away before they even have a chance to enter the geosphere. All canisters are designed to last at least several thousand years, if not much longer. This is enough time (>10 half-lives) to essentially eliminate Cs-137, Sr-90, Cm-244, as well as most of the Am-241 and some of the plutonium.

Durability of the waste form. Once canisters are breached, radionuclide releases may be limited by the degradation rate of the waste form in question; $U0_2$ (the main component of most used fuel) is relatively stable in reducing chemical environments and may degrade extremely slowly. Other waste forms, including borosilicate glasses, may also prove to be durable over long time periods.

Limited solubility of radionuclides. A number of radionuclides (e.g., Pu isotopes) that appear prominently in radiotoxicity index analyses have very low solubilities in waste forms and groundwaters. RI assumes 100% of the plutonium is dissolved, whereas only a tiny fraction of would be in solution after the disposal canister fails and groundwater enters the failed canister;

High sorption. Most of the radionuclides that contribute significantly to RI are moderately to strongly sorbed on both near-field (within the engineered repository) and far-field materials.. Sorption provides a delay in the transport of radionuclides from the repository to the biosphere, thereby allowing for additional decay time and lowering of calculated dose.

Accordingly, potential doses to a member of the public are typically found to be dominated by a handful of long-lived radionuclides with high mobilities and solubilities. For instance, Pu rarely, if ever, provides a significant contribution to the overall dose assessment for repository systems. In most TSPA analyses the potential doses are found to be dominated by long-lived, soluble and mobile fission products such as I-129, Tc-99, and Cl-36 that are only a trivial part of RI for either used fuel or intermediate and low-level waste (I/LLW) derived from advanced fuel schemes. Furthermore, such I/LLWs contain significant amounts of same problematic fission products, requiring deep geological disposal and additional dose assessment from TSPA analyses.

In this paper, sample TSPA analyses will demonstrate the inappropriateness of the RI approach and show the utility of a simplified radiological risk perspective to compare fuel cycles. Our approach draws on understanding the key risk-relevant radionuclides in the inventory, rather than those that contribute to hypothetical hazard outside the context of geological disposal.

CONCLUSION

The use of the radiotoxicity index (RI) as a figure of merit for justifying advanced fuel cycles involving separations technologies is not only inappropriate, but can be misleading with respect to judging benefits of advance fuel cycle options. The disposal system, through its use of multiple engineered and natural barriers to migration, eliminates most of the radionuclides contributing to the RI such that additional separations technologies will make little difference to peak dose rates. What must also be considered is the health/dose risk caused to workers and the public by the construction and operation of the separations facility itself. Thus, use of RI may lead to selection of separations technologies that may have a negligible effect on lowering the potential health risks associated with disposal, but will increase real worker and public health risks in the near term.