**Depleted Uranium Soaring Temperature Reactor (DUSTR)**

“Leaves other reactor designs in the dust!”

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**Depletion Analysis – Jacob Landman**

Depletion analysis is a very important component of this design process considering that one of the main goals of this reactor is to convert depleted uranium into fissile material. MCNP6 was used to burn the various versions of the reactor core. Each simulation was burned over a 50 year lifetime and for each depletion calculation the total core power was assumed to be ≈ 600 kW. Our analysis led to an estimate of the core lifetime and an estimate of the number of significant quantities of uranium and plutonium in both the depleted and LEU fuel assemblies. Ideally we would like the core lifetime to be very large in order to make this design more economically feasible. Additionally, a large core lifetime will decrease the long-term need for uranium enrichment, which helps with nonproliferation.

Figure (#.1) depicts the core criticality over 50 years for the first four versions of our core layout. We expected the criticality to increase initially as more and more depleted uranium is converted into fissile fuel. We also expected the criticality to reach a maximum value and then begin to decrease as the converted fissile material begins to deplete faster than it is being created. However, we observed an opposite trend. The criticality actually decreases initially as the LEU gets burned. After around 20 years, we begin to see the benefit of the conversion process as the criticality reaches a minimum and begins to increase. This discovery was one of the driving factors when coming up with new core layouts. We decided that our core criticality needed to never dip below 1.00 so that our reactor could theoretically operate upwards of 50 or so years.

Figure (#.1) shows that for all versions except for version 2, the criticality dips below 1. With versions 3 and 4, we attempted to force the core criticality to reach a minimum value more quickly. We used less LEU fuel assemblies and increased the enrichment to 20%. Unfortunately, the decrease of U-238 in the LEU led to a steeper decrease in criticality. As expected, the minimum criticality did occur earlier, but we were unable to prevent the criticality from dipping below 1.00. Based off these results, we decided that we should move forward with version 2 or some variation of version 2 (e.g. version 6).

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| Figure #.1. Core criticality over 50 years for the first four core layout versions |

Figure (#.2) depicts the criticality of version 6 over 50 years. The figure shows that over the core lifetime there are large reactivity changes. The changes in reactivity were calculated as follows:

Eq. (#.1)

where is the change in reactivity, and and are the criticalities at two different times. The delayed neutron fraction of Pu-239, β = 0.002, was used to convert the reactivity into dollars. The figure also shows that the criticality continues to increase as the burnup increases. This means that the reactor could operate for much longer than 50 years, assuming that the materials hold up and that the control elements can handle the excess reactivity.

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| Figure #.2. Core criticality over 50 years for version 6 |

The results seen thus far were obtained using burn steps equal to 1 year, which is extremely large. In order to validate these results, a burn using 2 week burn steps was performed on version 6. The results for this burn are displayed in figure (#.3). The results obtained using the smaller burn step appear to exhibit the same downward trend. It even seems that using a larger burn step may actually underestimate the core criticality, however this isn’t verified.

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| Figure #.3. Comparison of burn step size over 4 years |

As stated previously, it is important to know the material compositions at the end of lifetime (EOL) in order to quantify the amount of significant quantities of uranium and plutonium within the fuel. Figure (#.4) displays an excerpt from the IAEA Safeguards Glossary. The figure shows that a significant quantity of plutonium is 8 kg of Pu containing less than 80% Pu-238 and a significant quantity of uranium is 75 kg of U-235 that is less than 20% enriched. With this information, it is clear that we need to know the fraction of U-235 and Pu-238. Tables #.1 and #.2 display the plutonium and uranium quantities, respectively.

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| Figure #.4. Excerpt from IAEA Safeguards Glossary regarding significant quantities |

The tables show that the plutonium concentration is far below 20% Pu-238, which means we do indeed care about the amount of plutonium at the end of the core lifetime. Also, the average uranium enrichment throughout the core is well below 20%, which means one would need 75 kg of uranium in order to have a significant quantity. The tables also display the total mass of each of the isotopes. Clearly, there are numerous significant quantities within the entire core.

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| Table #.1 | | | | |
| Plutonium Quantities | | | | |
| **Isotope ID** | **BOL** | | **EOL** | |
| **Mass (kg)** | **Mass Fraction** | **Mass (kg)** | **Mass Fraction** |
| 94236 | 0.0000 | 0.0000 | 0.0001 | 0.0000 |
| 94237 | 0.0000 | 0.0000 | 0.0001 | 0.0000 |
| **94238** | 0.0000 | 0.0000 | **78.8400** | **0.0119** |
| **94239** | 0.0000 | 0.0000 | **5096.0000** | **0.7666** |
| **94240** | 0.0000 | 0.0000 | **1321.0000** | **0.1987** |
| 94241 | 0.0000 | 0.0000 | 124.8000 | 0.0188 |
| 94242 | 0.0000 | 0.0000 | 27.3000 | 0.0041 |

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| Table #.2 | | | | |
| Uranium Quantities | | | | |
| **Isotope ID** | **BOL** | | **EOL** | |
| **Mass (kg)** | **Mass Fraction** | **Mass (kg)** | **Mass Fraction** |
| 92233 | 0.0000 | 0.0000 | 0.0015 | 0.0000 |
| 92234 | 5.5000 | 0.0001 | 12.8300 | 0.0002 |
| **92235** | **2343.0000** | **0.0292** | **62.9300** | **0.0010** |
| 92236 | 0.0000 | 0.0000 | 244.0000 | 0.0039 |
| 92237 | 0.0000 | 0.0000 | 0.1010 | 0.0000 |
| **92238** | **77770.0000** | **0.9707** | **61590.0000** | **0.9948** |
| 92239 | 0.0000 | 0.0000 | 0.0156 | 0.0000 |
| 92240 | 0.0000 | 0.0000 | 0.0000 | 0.0000 |

To better quantify the amount of significant quantities, figure (#.5) displays the number of plutonium significant quantities in one fuel assembly for both the LEU and depleted fuel over the core lifetime. Without a doubt, there is a large number of significant quantities contained within 1 fuel assembly of depleted uranium. With this knowledge, it is imperative for the physical security to be able to prevent criminals from obtaining these materials. Figure (#.6) displays the number of fuel elements that would be needed in order to have 1 significant quantity of plutonium. As expected, at the beginning of core operation, the number of elements needed is quite high, but the longer the core operates, fewer fuel elements are needed. Once again, the physical security at the reactor facility, will need to prevent criminals from obtaining the number of elements needed to have a significant quantity of plutonium.

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| Figure #.5. Plutonium significant quantities per assembly |

Figures (#.7) displays the significant quantities of U-235 in the entire core. The figure shows that there is a very small amount of U-235 significant quantities. Figure (#.8) bares this out by displaying the significant quantities per assembly. This figure shows that not one assembly contains a significant quantity of U-235. Thus, from a safeguards perspective, U-235 is not much of a concern.

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| Figure #.6. Number of fuel elements needed for 1 significant quantity |

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| Figure #.7. Significant quantities of U-235 in the entire core |

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| Figure #.8. Significant quantities of U-235 per assembly |