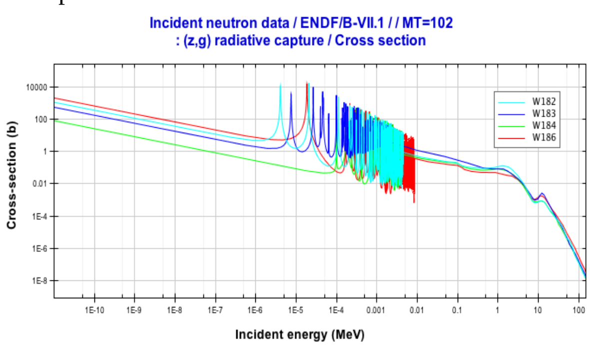
NEUTRONIC ANALYSIS OF A TUNGSTEN CERMET LEU-NTR C. G. Rosaire IV[1], P. Husemeyer[2], W. Deason[3], and P. Venneri[4], [1]Texas A&M University (grfour@tamu.edu), [2]University of Cambridge, [3]Center for Space Nuclear Research, [4]Korea Advanced Institute for Science and Technology.

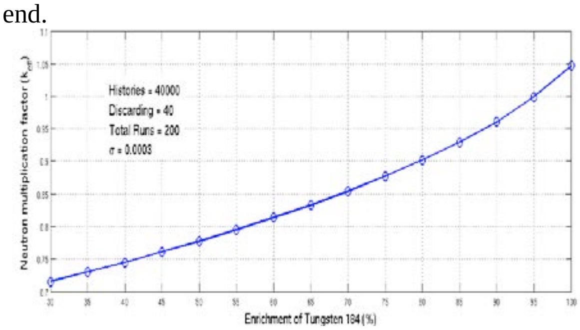
Introduction: Nuclear rocket engines (NRE) have the ability to dramatically increase human space flight capability beyond low-earth-orbit, and this is due to the decrease in specific fuel consumption of the NRE compared to LH_2/LO_2 rocket engines (~900s v. 450s) [1].

NASA has inquired into the viability of LEU fueled space reactors, due in part to the Department of Energy's (DOE) Global Threat Reduction Initiative (GTRI), which seeks to limit the use of highly enriched uranium (HEU) in the civilian sector [2]. This has led to the effort to design a viable NRE that falls into NASA's requirements for a NRE [3].

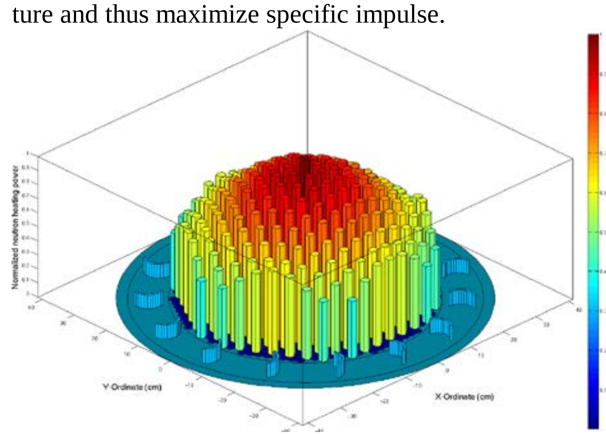
Tungsten Enrichment: Tungsten has four naturally occurring isotopes, of which, only one has a low enough neutron capture cross-section to enable a thermal spectrum reactor. This isotope is ^{184}W and its cross-section is plotted with the other naturally occurring isotopes to show the relative magnitude of the absorption cross-sections.



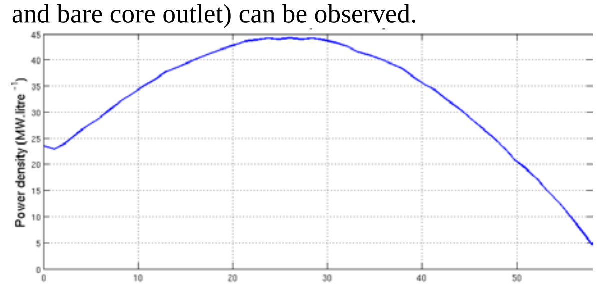
MCNPX 2.7 was used to determine various aspects of the neutronic characteristics of the NRE [4]. All of the calculations were performed in the "cold, clean" state. The ^{184}W enrichment was varied to determine the extent of enrichment that would be necessary for a tenable reactor design. The figure below demonstrates the necessity for enrichment with natural tungsten at the left extreme of the graph and fully enriched at the right-end.



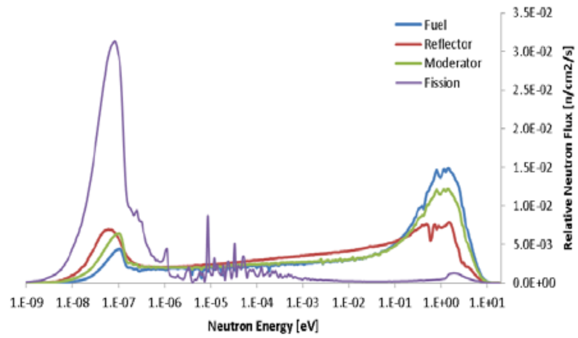
Radial Power Profile: This is evidenced in the figure below where the relative normalized power of each fuel element is displayed. The control surfaces of the control drums are exaggerated in order to show that there is some energy deposition outside of the active core. Here it is clear the power profile of the reactor has a significant power peaking in the center of the reactor. The radial peaking factor of 1.43 demonstrates the need for radial power profile flattening in future work in order to maximize the rocket outlet temperature and thus maximize specific impulse.



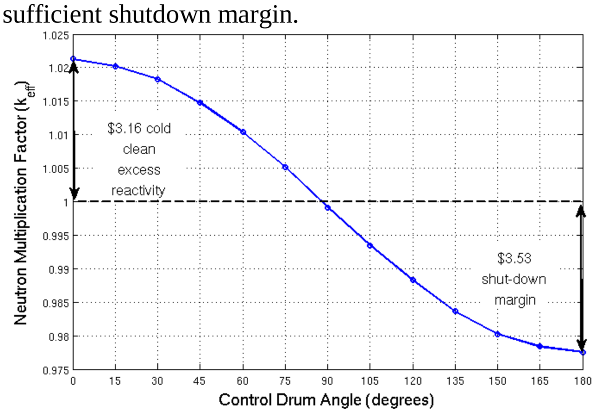
Axial Power Profile: Axial tallies were performed for the highest power fuel element and for the neighboring tie-tubes. Within each tie-tube, neutron and photon energy deposition tallies were performed for each constituent material, therefore allowing an in-house finite difference model to use source terms for each material. The axial power density profile for the central fuel element is shown in the figure below where the shifted cosine shape (due to the inlet side reflector and bare core outlet) can be observed.



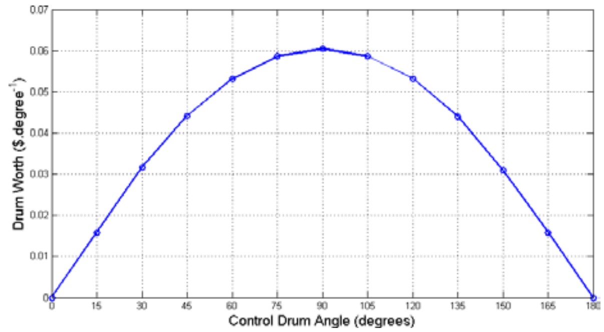
Neutron Energy Dependence: The LEU-NTR requires a thermal neutron energy spectrum due to the low fissile content of the fuel and the small form factor of the engine. This presented some challenges in that the LEU-NTR required nine times as much moderator as the Small Nuclear Rocket Engine (SNRE) [5]. The neutron energy spectrum for the average of the fuel, moderator, the reflector zones, and the fission energy per neutron energy spectrum is given in the figure below.



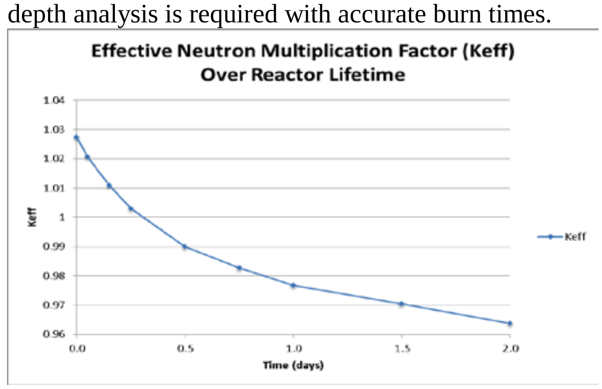
Reactivity Control: Reactivity control of the reactor core is achieved by 15 beryllium-metal control drums with 5 mm of B4C over a 120-degree arc of the cylinder's surface. The control drums are in the most reactive position with the B4C rotated out of the reactor and the most subcritical with the drums rotated inside. The figure below shows the incremental change in the neutron multiplication factor as the drums are rotated through the limits of their travel. This figure displays the characteristic "S" curve of reactivity, in which the highest differential worth of the control drums is approximately midway through control drum travel. The entire control system has a total of $6.69 of control worth, which is sufficient for the low operational lifetime to bring the reactor up to power and sufficient shutdown margin.



Differential reactivity worth. The figure (top-right) shows the differential control drum worth for all control drums, and peak drum worth is achieved at 90 degrees with 6 cents of reactivity per degree of control drum rotation.



Burnup: The fuel burnup is currently the most limiting factor; as can be seen in the figure below, the reactor becomes subcritical within the first six hours at full power. This indicates the need for many more fuel elements to be incorporated into the reactor design. The reactor is at 0.47 GWd/MTU burnup at the six-hour mark when it begins to fall subcritical. This is due to xenon poisoning in the fuel, therefore a more in-depth analysis is required with accurate burn times.



Summary: The current reactor design demonstrates the viability of the LEU-NRE concept for moving forward in NASA technology down-selection. Only minor modifications to the design are required for adequate lifetime.

References: [1] Stanley K. Borowski, David R. McCurdy, and Thomas W. Packard, "Nuclear Thermal Rocket (NTR) Propulsion: A Proven Game-Changing Technology for Future Human Exploration Missions," in Global Space Exploration Conference, Washington D.C., 2012. [2] National Nuclear Secutity Administration, nnsa.energy.gov. [3] Michael G. Houts, Tony Kim, and et al, "A Nuclear Cryogenic Propulsion Stage for Near-Term Space Missions," in *Proceedings of Nuclear and Emerging Technologies for Space 2013*, Albuquerque, NM, 2013. [4] X-5 Monte Carlo Team, Los Alamos National Laboratory, MCNP — A General Monte Carlo N-Particle Transport Code, Version 5, 2008. [5] Bruce G. Schnitzler and Stanley K. Borowski, "Small Reactor Designs Suitable for Direct Thermal Propulsion," AIAA 2012-3958, 2012.