SAND2012-6064P

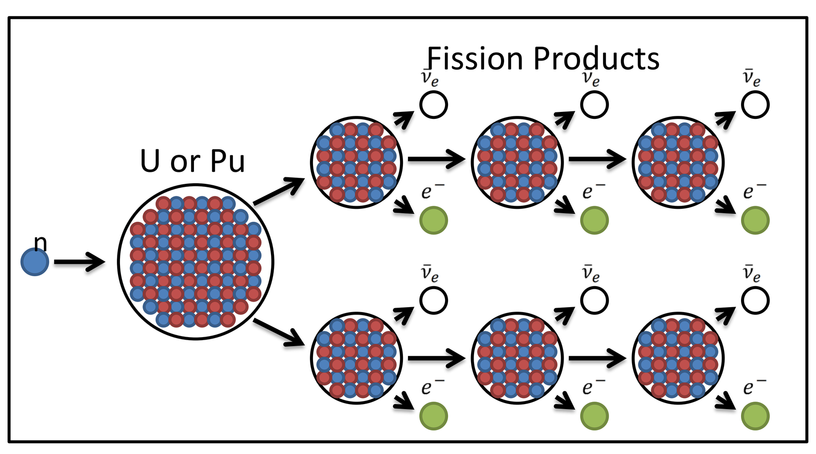
Analysis of the Antineutrino Signature of LEU/MOX Fueled LWRs

Thomas G. Saller[1,2], Andrew M. Ward[1], David Reyna[2], Scott Kiff[2], Thomas J. Downar[1]
1. University of Michigan, Ann Arbor, MI, 2. Sandia National Laboratories, Livermore, CA

Motivation

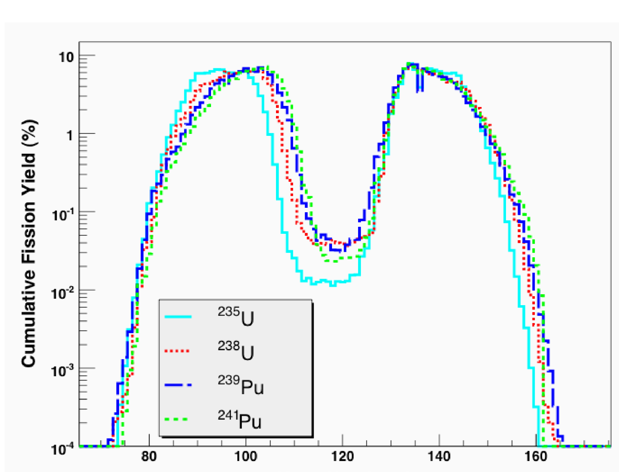
Antineutrino detectors provide an external technique for reactor power monitoring. In addition, by using differences in antineutrino yields between isotopes, antineutrino detection can be used to differentiate between LEU and MOX fuels. Parametric reactor simulations must be performed to evaluate the effectiveness of this technique for diversion scenarios.

Antineutrinos and Reactors



Antineutrinos are produced in nuclear reactors from the beta decay of fission products. On average, six are produced per fission.

Fission product yields are isotope dependent. Therefore the energy distribution for antineutrinos are also isotope dependent.



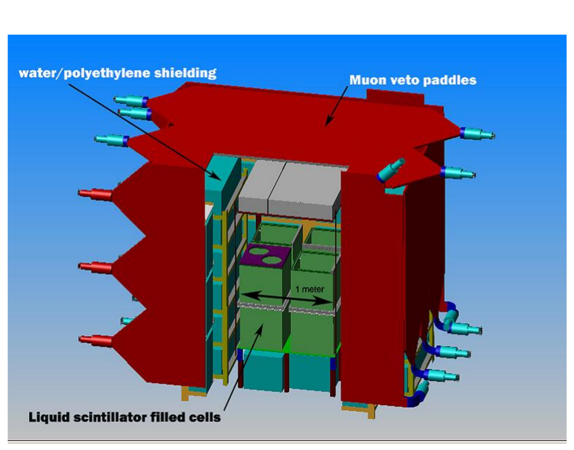
Isotopes	# ν_e above 1.8 MeV[1]
^{235}U	1.92(1 ± 0.019)
^{238}U	2.38(1 ± 0.020)
^{239}Pu	1.45(1 ± 0.021)
^{241}Pu	1.83(1 ± 0.019)

Only antineutrinos above the threshold energy 1.8 MeV can be detected. The average number for each isotope is given.

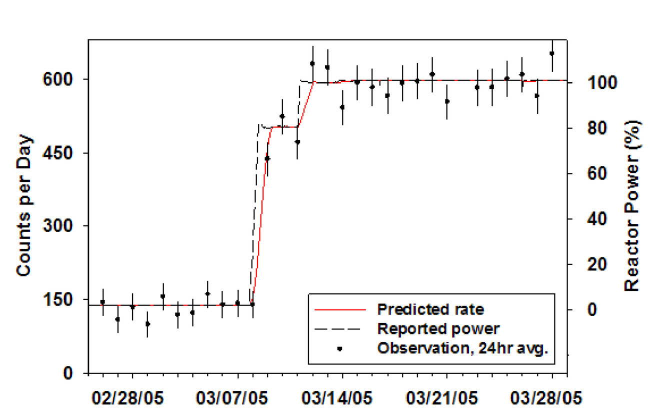
Antineutrino Detection

Antineutrino undergoes inverse beta decay, a reaction that has a cross-section on the order of 10^{-43} cm^3. The neutron and positron from this reaction are then detected as correlated events.

Inverse beta decay: $\bar{\upsilon}_e + p \rightarrow n + e^+$



Sample antineutrino detector used for power monitoring.[3]



San Onofre Nuclear Generating Station (SONGS) detector showing the difference in antineutrino rates between reactor off and on.[4]

Simulations to Antineutrinos

Antineutrino rates are calculated using fission rates from the reactor physic codes HELIOS and PARCS and average antineutrino yields.

ϕ_g	Group g neutron flux
$\sigma_{f,i,g}$	Group g microscopic fission cross-section
N_i	Number densities for isotope i
$\bar{\upsilon}_i$	Average antineutrino yield for isotope i

$$\upsilon_i = \bar{\upsilon}_i \sum_{g=1}^{2} N_i \sigma_{f,i,g} \phi_g$$

$$\upsilon_{tot} = \sum_i \upsilon_i$$

Definitions

Burnup – a measure of the energy extracted from a mass of fuel (e.g. gigawatt-days per metric ton heavy metal, or GWd/MTHM).

Low-enriched uranium (LEU) – uranium which has been enriched in weight percent ^{235}U, typically between 2 and 5%.

Mixed oxide fuel (MOX) – nuclear fuel containing more than one oxide of fissile material. In this case, plutonium oxide and (depleted) uranium oxide.

Weapons-grade (WG) plutonium – plutonium highly enriched in ^{239}Pu, with less than 7 weight percent ^{240}Pu.

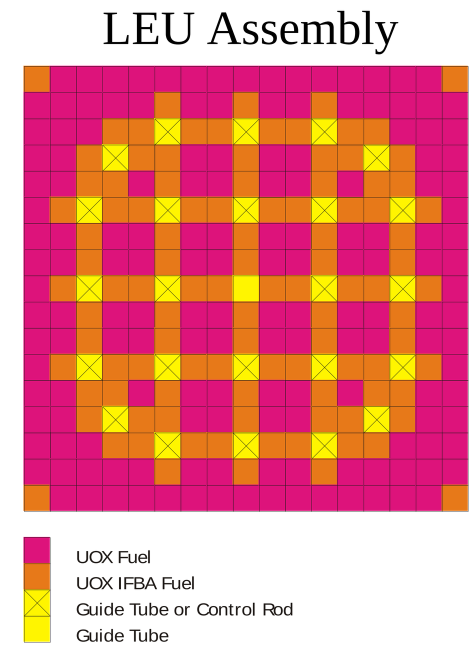
Reactor-grade (RG) plutonium – plutonium with an isotopic composition characteristic of that found in spent fuel, with at least 19 weight percent ^{240}Pu.

Control Rod (CR) – a rod made of a strong neutron absorber that is used to control fission rates in a nuclear reactor.

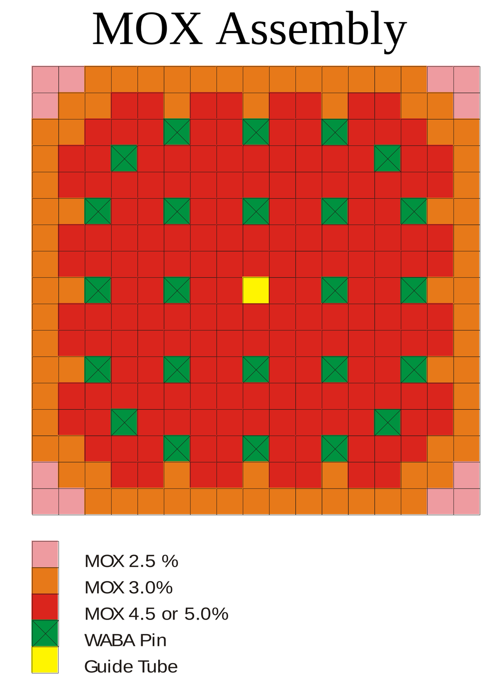
Fuel Assembly – a structured group of fuel rods containing fissionable material. A nuclear power plant contains tens to hundreds of fuel assemblies.

Fuel Assemblies

LEU Assembly



MOX Assembly

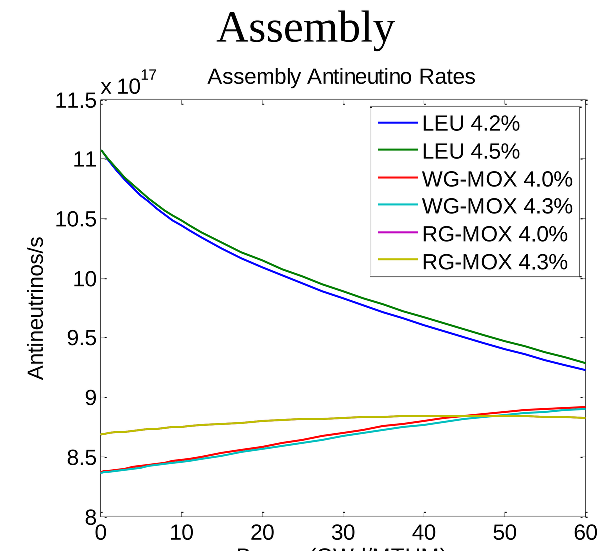


Isotopic Compositions, 4.0% enriched (wt% ^{235}U or Pu)

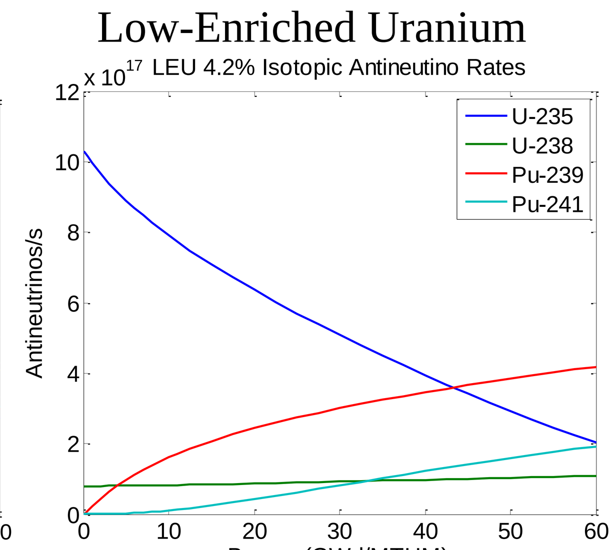
Isotope	RG MOX	WG MOX	LEU
U-235	0.192	0.192	4
U-238	95.80512	95.80512	96
Pu-239	2.168	3.744	0
Pu-241	0.504	0.016	0

Assembly Results

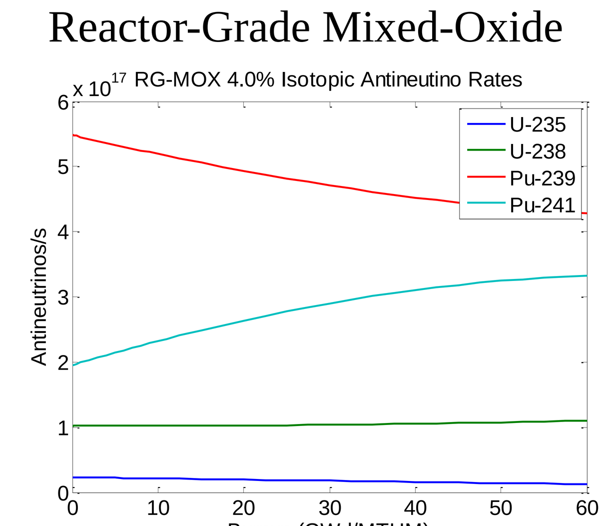
Assembly



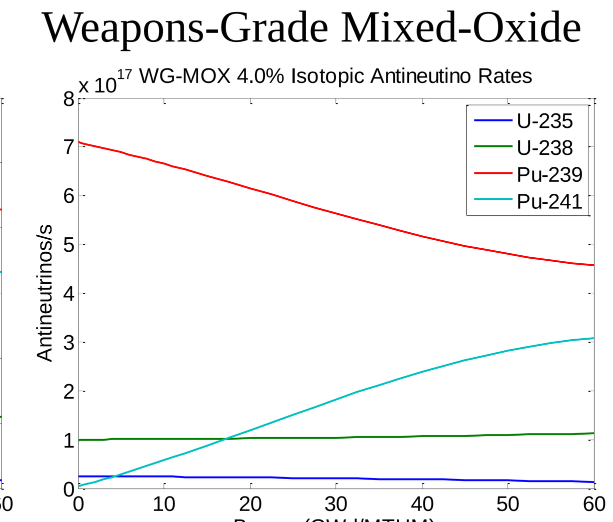
Low-Enriched Uranium



Reactor-Grade Mixed-Oxide

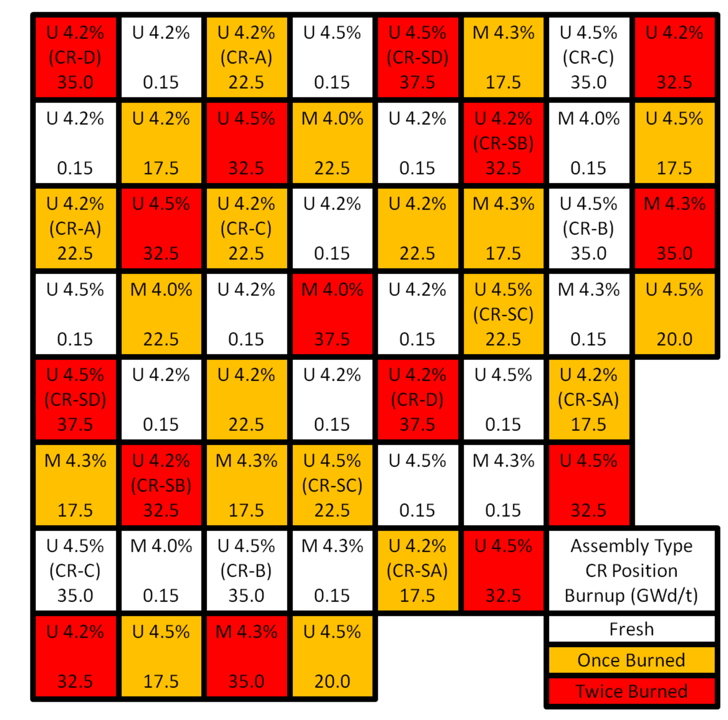


Weapons-Grade Mixed-Oxide

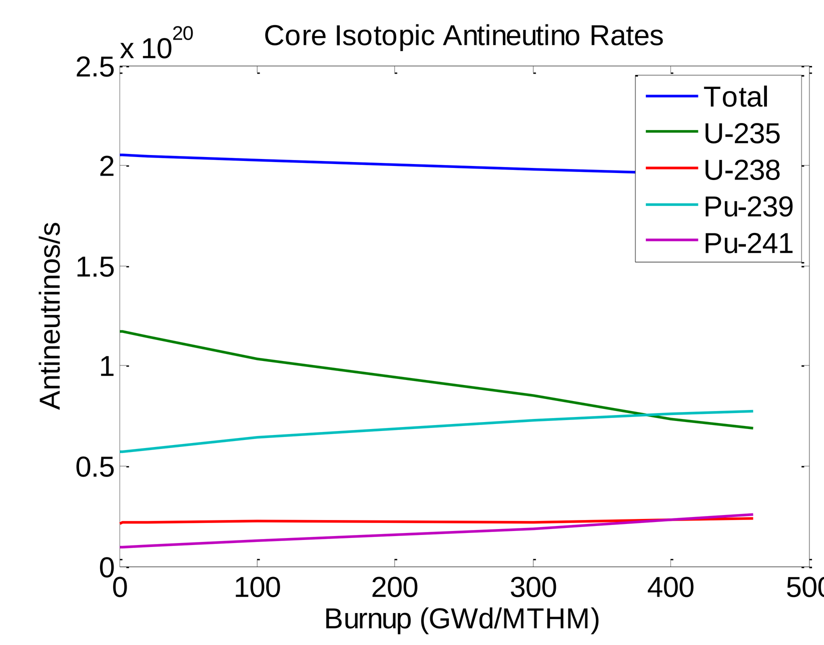


The differences between antineutrino production for LEU, WG-MOX, and RG-MOX assemblies as seen in the top-left plot are further explained by examining their isotopic rates shown in the other three plots.

Benchmark MOX Core[2]

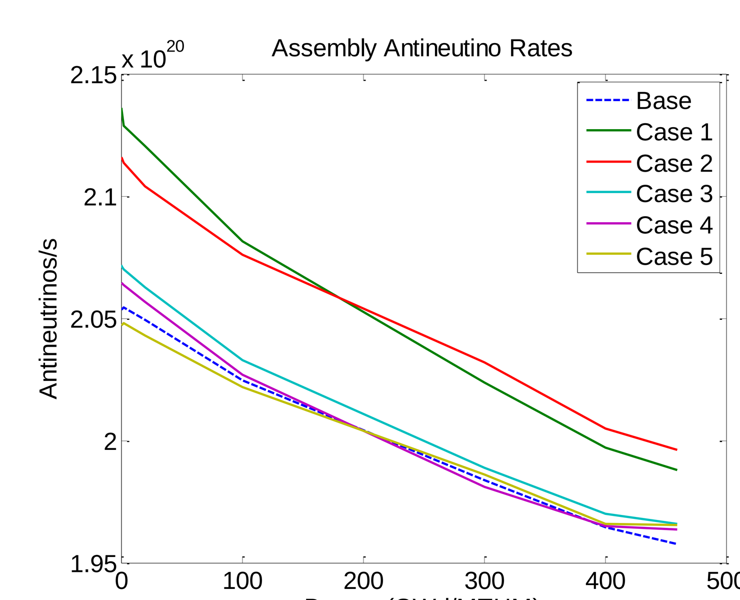


Pictured: One quarter of the full core. The core has four assembly types: two LEU enrichments and two MOX enrichments, at three different burnups, fresh, once burned, and twice burned, to represent an equilibrium state.



Parametrics

Case 1 – replace all WG-MOX 4.0% with fresh LEU 4.5%
Case 2 – replace all fresh WG-MOX with fresh LEU 4.5%
Case 3 – replace all fresh WG-MOX with fresh RG-MOX
Case 4 – Add in CR-B (towards periphery, 8 assemblies)
Case 5 – Add in CR-A (towards inside, 4 assemblies)



Replacing a single fresh WG-MOX assembly with RG-MOX has between a 0.045% and 0.021% difference depending on the power at that location.

Conclusions

Due to differences in isotopic antineutrino yields, different assembly types can vary significantly in their antineutrino signatures. When translated to a full core, these effects can be magnified or reduced depending on the power of the assemblies in question relative to the total reactor power. The relative power of an assembly is dependent on several factors, including its fuel composition, burnup, location in the core, and control rod insertion.

Replacing MOX assemblies with LEU assemblies produces the greatest change in antineutrino production, while inserting control rods produces a small change in the total output while greatly affecting local burnup.

References/Acknowledgments

This work was supported by the NNSA SSGF administered by Krell.

1. P. Huber and T. Schwetz, "Precision spectroscopy with reactor antineutrinos," *Physical Review D*, ***70*, 053011 (2004).**
2. T. Kozlowski, T. J. Downar, R. Lee, "OECD PWR MOX Core Transient Benchmark," GLOBAL 2003, New Orleans, Georgia, U.S.A. (2003).
3. N. S. Bowden, et al., "Observation of the isotopic evolution of pressurized water reactor fuel using an antineutrino detector," *Journal of Applied Physics*, **105**, 064902 (2009).
4. Cooperative Monitoring of Reactors Using Antineutrino Detectors – Report on Progress

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.
SAND No. 2011-XXXXP