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Analysis of the Antineutrino Signature of LEU/MOX Fueled LWRs

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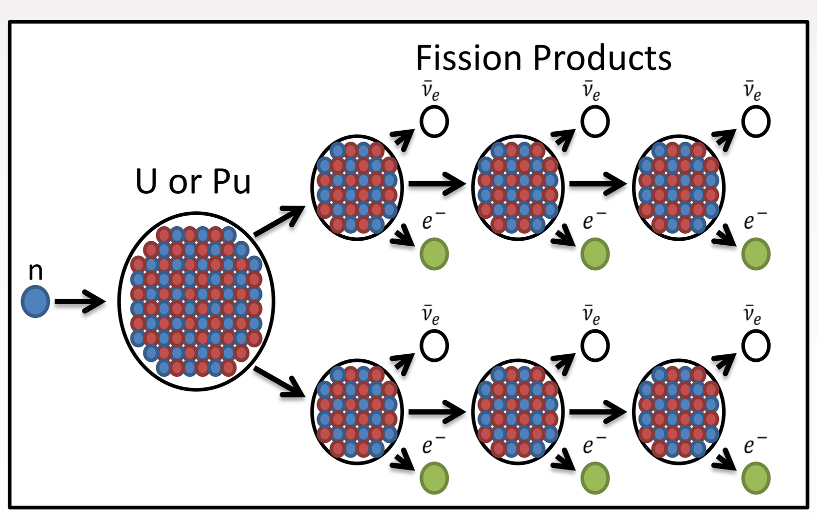
Abstract

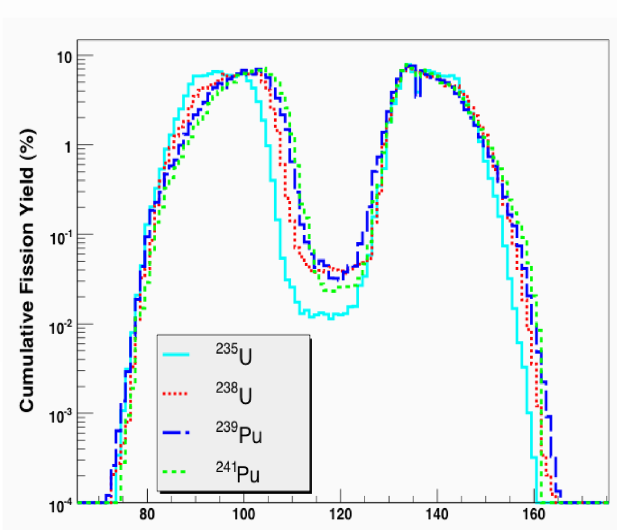
Differences in antineutrino production from a nuclear reactor can be used to determine whether the reactor is loaded with low-enriched uranium (LEU) or mixed-oxide (MOX) fuel and to discriminate between weapons-grade and reactor-grade MOX fuel. An analysis of the time-dependent antineutrino production rates for MOX and mixed LEU/MOX cores is performed with the HELIOS/PARCS code package for an equilibrium MOX core and a series of parametrics. A 4% difference is seen when replacing WG-MOX with LEU versus a 0.8% difference when replacing WG-MOX with RG-MOX. Both results indicate that in-core conditions have a large influence on antineutrino production when compared to single fuel assembly results.

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.



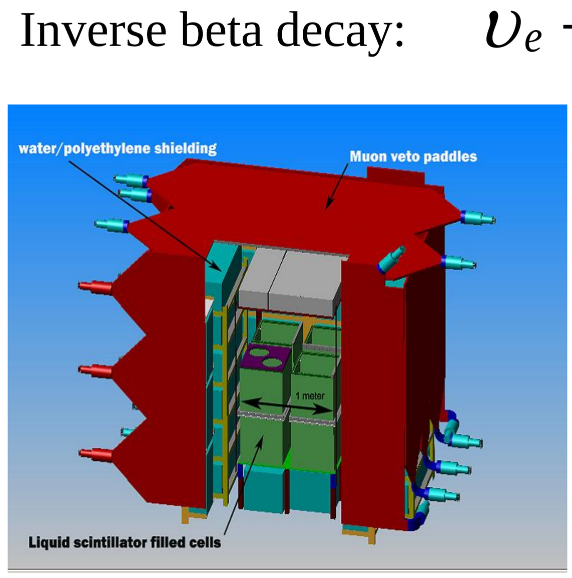
Isotopes	# ν_e above 1.8 MeV[1]
^{235}U	1.92(1 ± 0.019)
^{238}U	2.38(1 ± 0.020)
^{239}Pu	1.45(1 ± 0.021)
^{241}Pu	1.83(1 ± 0.019)

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

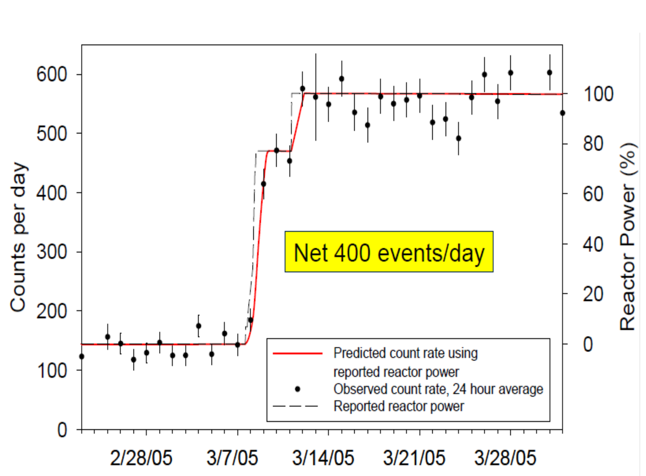
Antineutrino Detection

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: $\bar{\nu}_e + p \rightarrow n + e^+$



Power monitoring with antineutrinos.[3]



San Onofre Nuclear Generating Station (SONGS) detector.[4]

Definitions

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

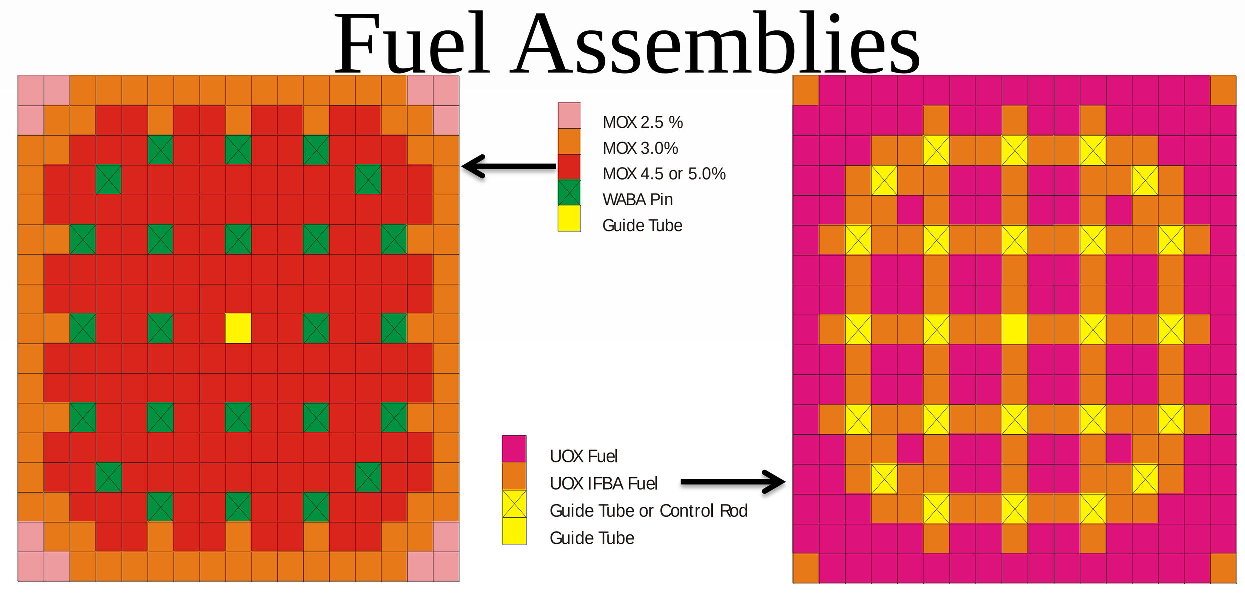
Low-enriched uranium (LEU) – uranium which has been enriched in weight percent ^{235}U, typically between 2 and 5%

Mixed oxide fuel (MOX) – nuclear fuel containing plutonium and uranium (in our case depleted uranium)

Weapons-grade (WG) plutonium – plutonium highly enriched in ^{239}Pu, particularly relative to ^{240}Pu

Reactor-grade (RG) plutonium – plutonium with an isotopic composition characteristic of that found in spent fuel, generally with more ^{240}Pu, ^{241}Pu, and ^{242}Pu than is found in WG Pu

Fuel Assemblies

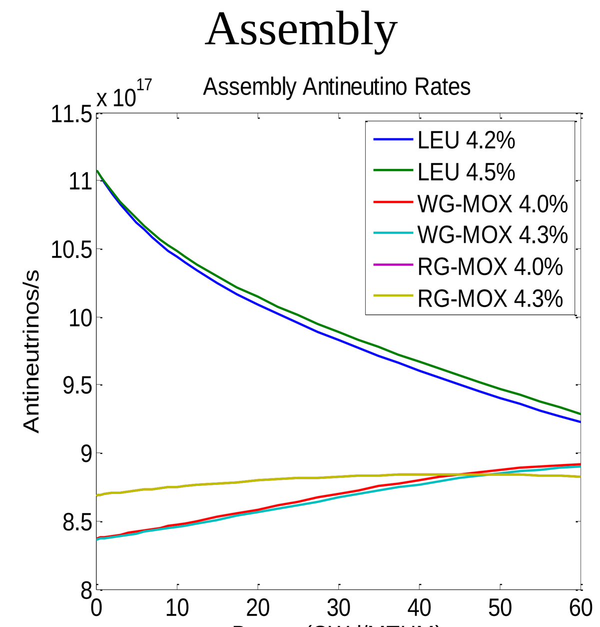


Isotopic Compositions, 4.0% enriched (wt% ^{235}U or Pu)

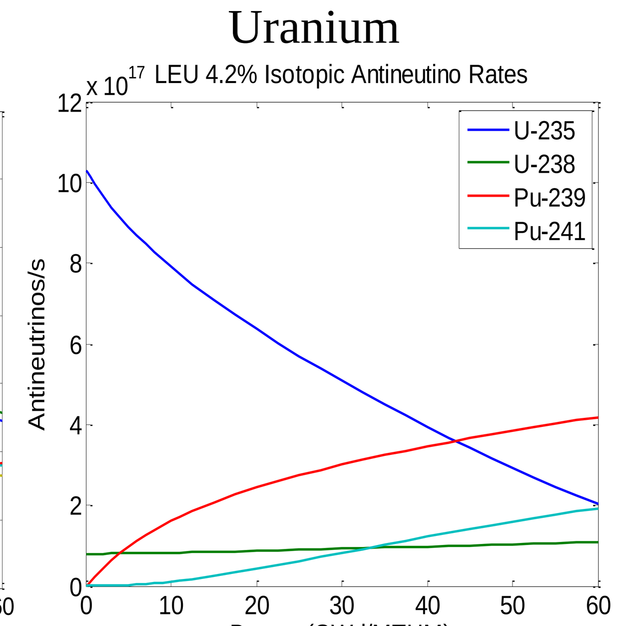
Isotope	RG MOX	WG MOX	LEU
U-235	0.192	0.192	4
U-238	95.80512	95.80512	96
Pu-239	2.168	3.744	0
Pu-241	0.504	0.016	0

Assembly Results

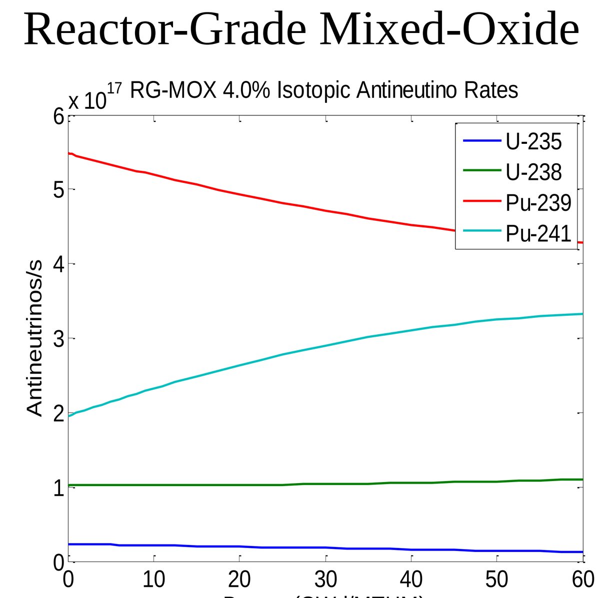
Assembly



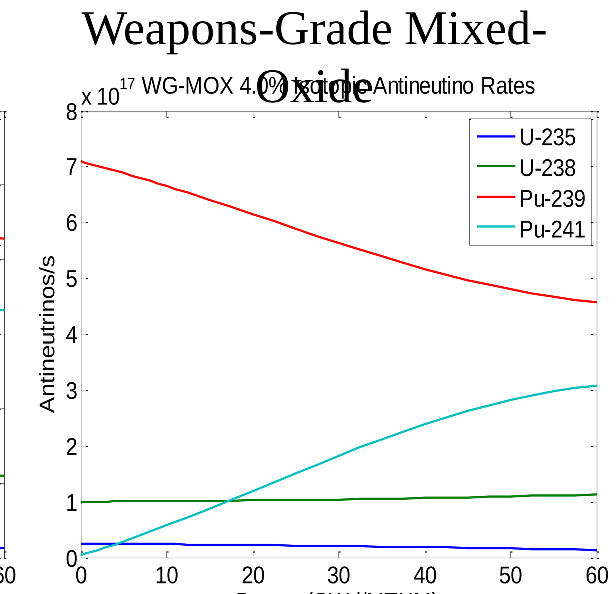
Uranium



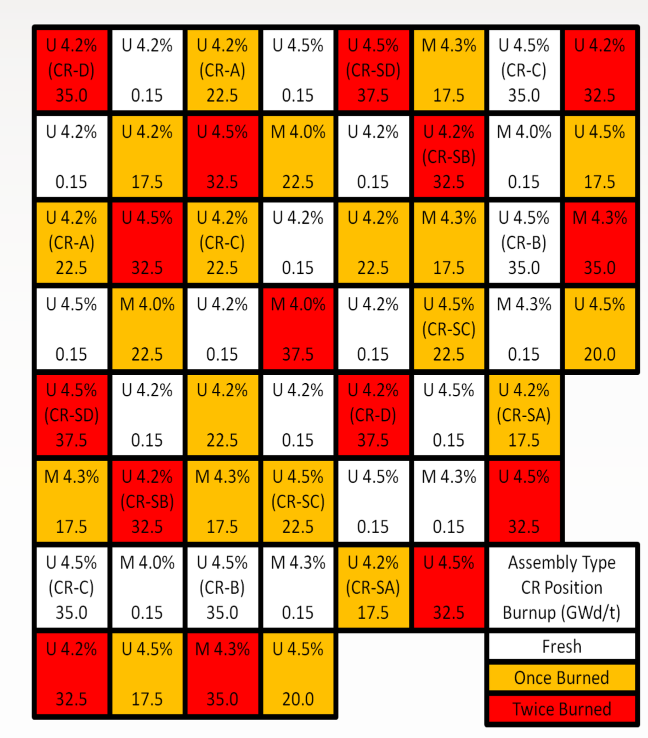
Reactor-Grade Mixed-Oxide



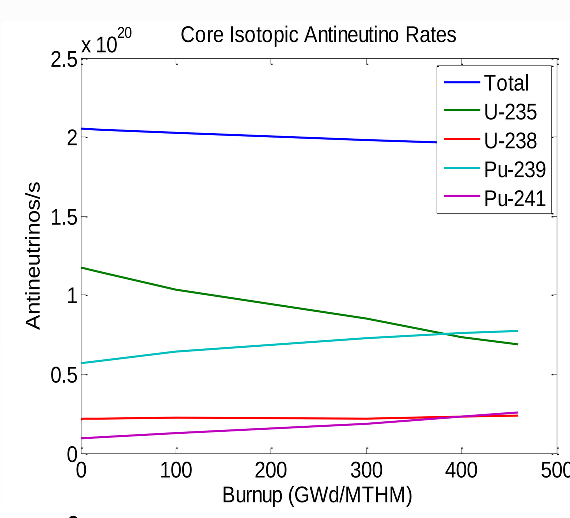
Weapons-Grade Mixed-Oxide



Benchmark MOX Core[2]

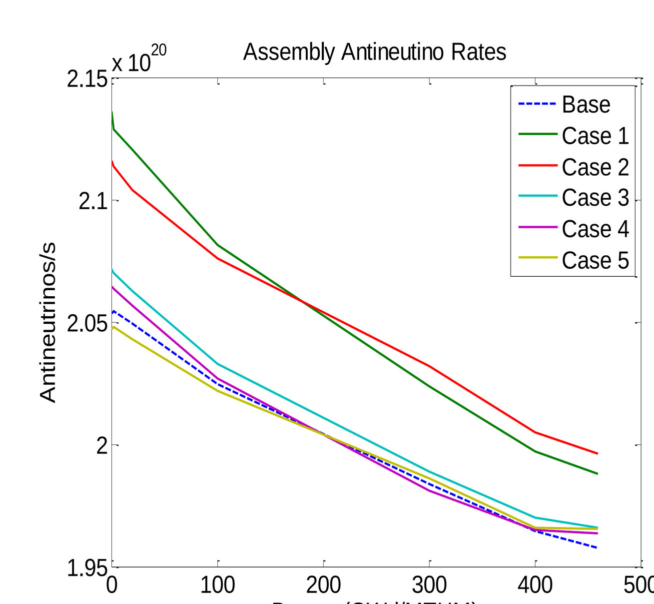


The core has four assembly types: two LEU enrichments and two MOX enrichments, at three different burnups, fresh, once burned, and twice burned.



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 relative power of the assemblies in question.

References/Acknowledgments

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2. T. Kozlowski, T. J. Downar, R. Lee, "OECD PWR MOX Core Transient Benchmark," GLOBAL 2003, New Orleans, Georgia, U.S.A. (2003).
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4. Cooperative Monitoring of Reactors Using Antineutrino Detectors – Report on Progress