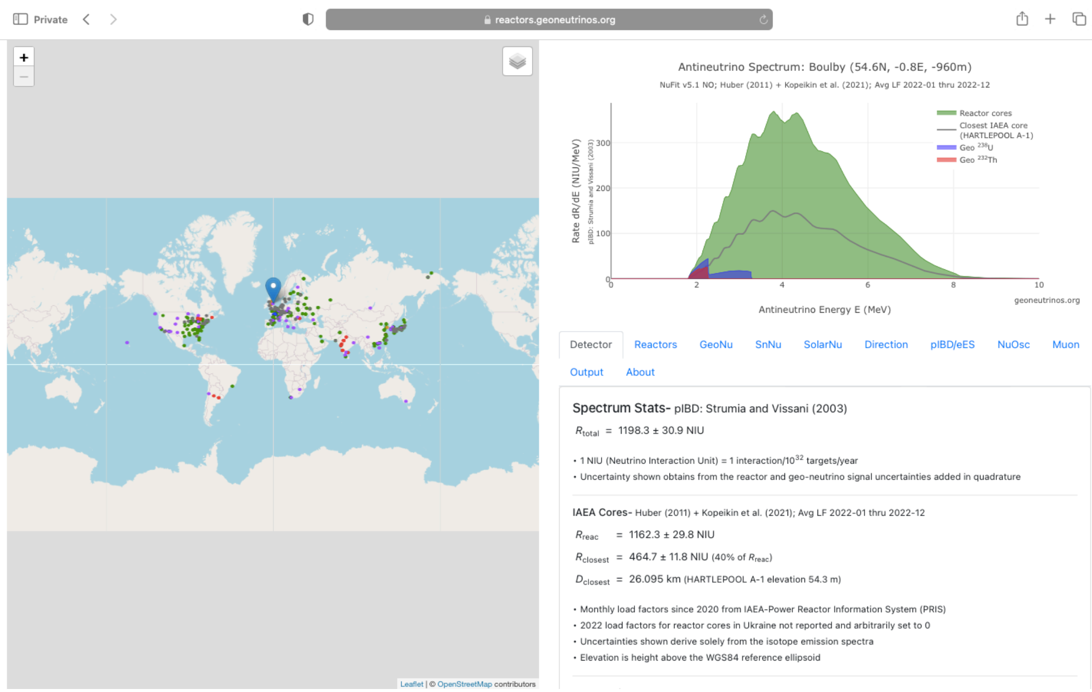
Estimating Neutrino Signals with geoneutrinos.reactors.org



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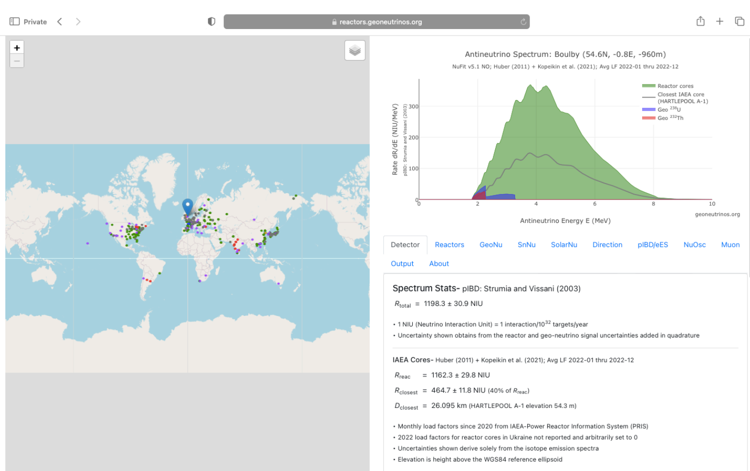
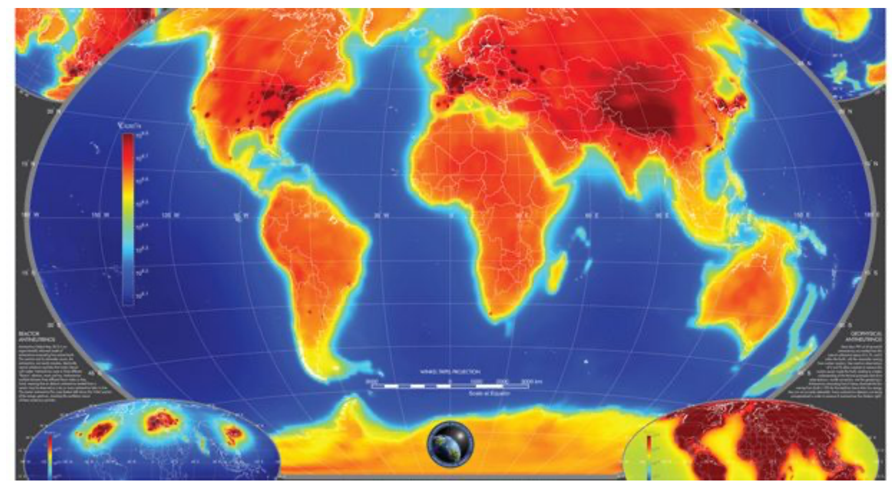
Objective

- Develop and maintain an online tool that estimates antineutrino signals from nuclear power reactors and Earth to serve the scientific and non-proliferation communities

- https://reactors.geoneutrinos.org/

- Interactive tool… complementary to static maps

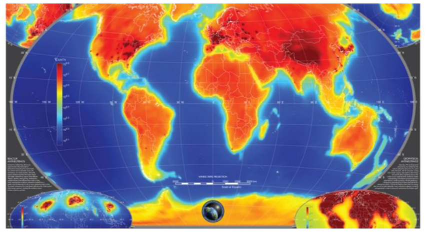


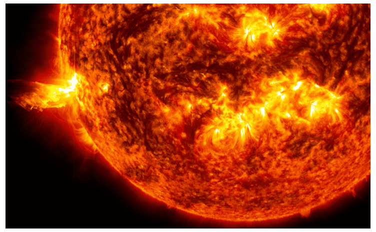


Overview

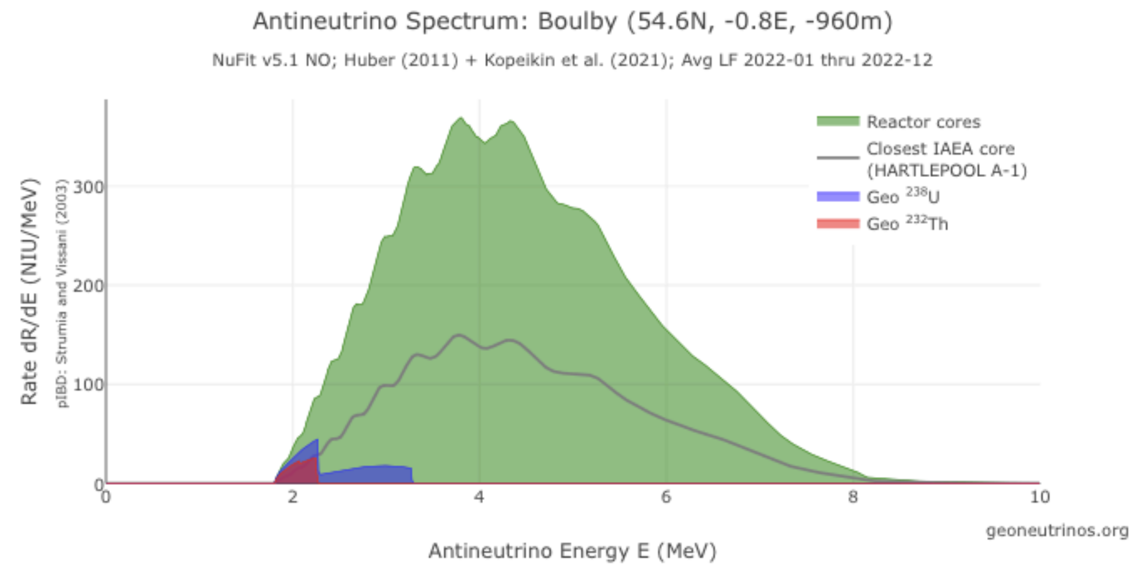
- Signal estimator with user-interface and documentation
- Rates and spectra anywhere on Earth- dynamic
- Set locations, enter lat/lon/elev, cursor on map, laptop w/ GPS
- Downloadable plots and energy spectra
- Signal significance calculator, user-defined detection efficiency
- Background information being added

Sources and Reactions





- Sources: power reactors and geo, also SN burst, ^{8}B solar
- Reactions: free-proton IBD (pIBD), electron ES (eES)
- Rates in units of 10^{32} targets / year
- SN burst (10s) include pIBD, eES, pES, CEvNS, IBD of ^{16}O, ^{12}C
- CEvNS rates for 1000 kg



Detector | Reactors | GeoNu | SnNu | SolarNu | Direction | pIBD/eES | NuOsc | Muon | Output | About

Spectrum Stats- pIBD: Strumia and Vissani (2003)

R_{total} = 1198.3 ± 30.9 NIU

- 1 NIU (Neutrino Interaction Unit) = 1 interaction/10^{32} targets/year
- Uncertainty shown obtains from the reactor and geo-neutrino signal uncertainties added in quadrature

IAEA Cores- Huber (2011) + Kopeikin et al. (2021); Avg LF 2022-01 thru 2022-12

R_{reac} = 1162.3 ± 29.8 NIU

$R_{closest}$ = 464.7 ± 11.8 NIU (40% of R_{reac})

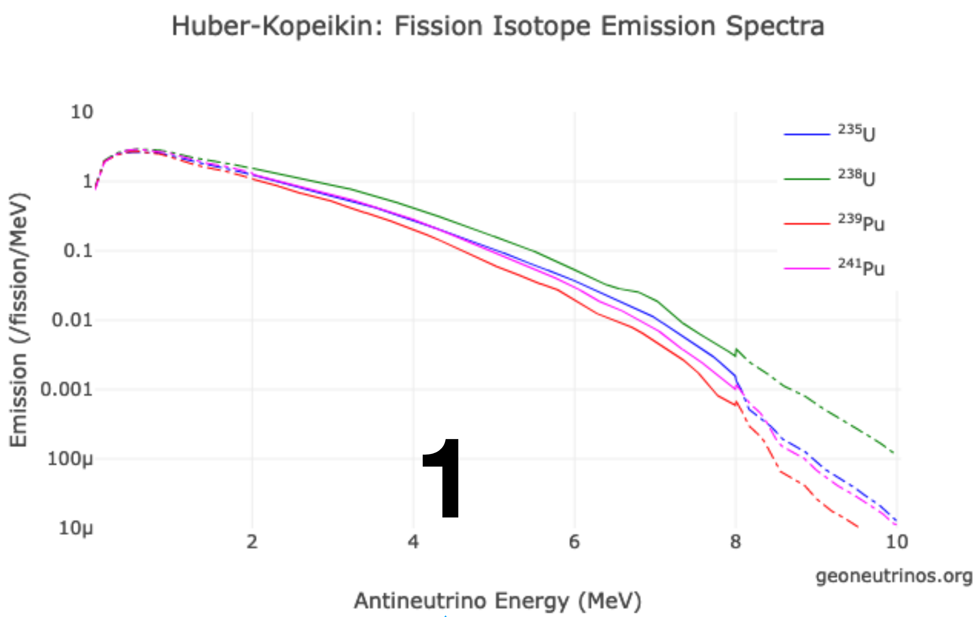
$D_{closest}$ = 26.095 km (HARTLEPOOL A-1 elevation 54.3 m)

- Monthly load factors since 2020 from IAEA-Power Reactor Information System (PRIS)
- 2022 load factors for reactor cores in Ukraine not reported and arbitrarily set to 0
- Uncertainties shown derive solely from the isotope emission spectra
- Elevation is height above the WGS84 reference ellipsoid

Reactors

- Monthly load factors for 399 IAEA cores active in 2022 (w/o Ukraine)
- Custom cores presets include research reactors, geo-reactor, + user-defined
- ^{235}U, ^{238}U, ^{239}Pu, ^{241}Pu emission spectra 0-10 MeV
  - selectable spectra using conversion, summation, *ab initio*
- fixed fission energies, mid-cycle fission fractions PWR/BWR, PHWR, MOX
- latest NuFit v5.1 oscillation parameters with switchable mass ordering
- IBD cross section: Strumia and Vissani (2003) **or** Vogel and Beacom (1999)
- ES cross section: antineutrino, **or** nubar_e, **or** nubar_x

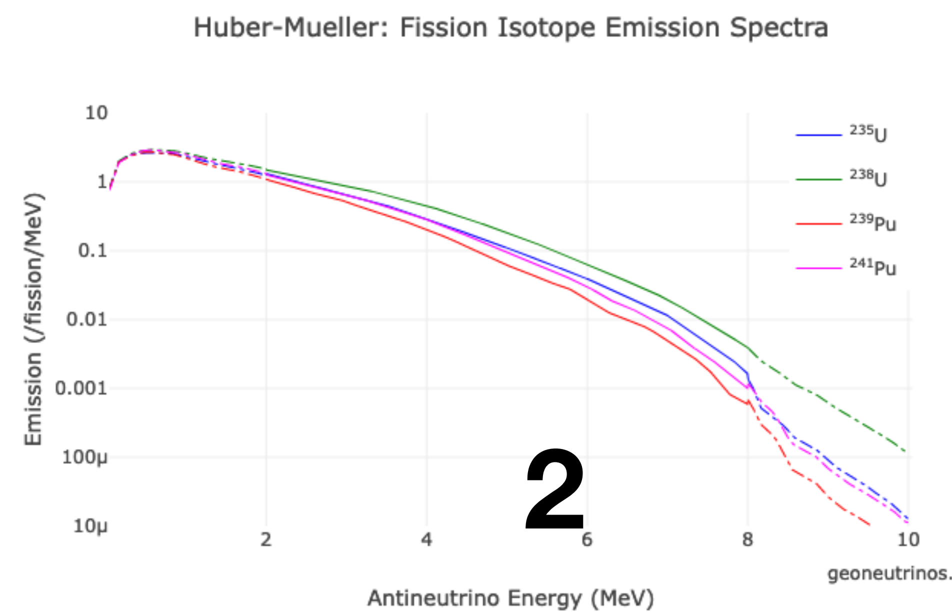
Reactor Isotope Emission Spectra

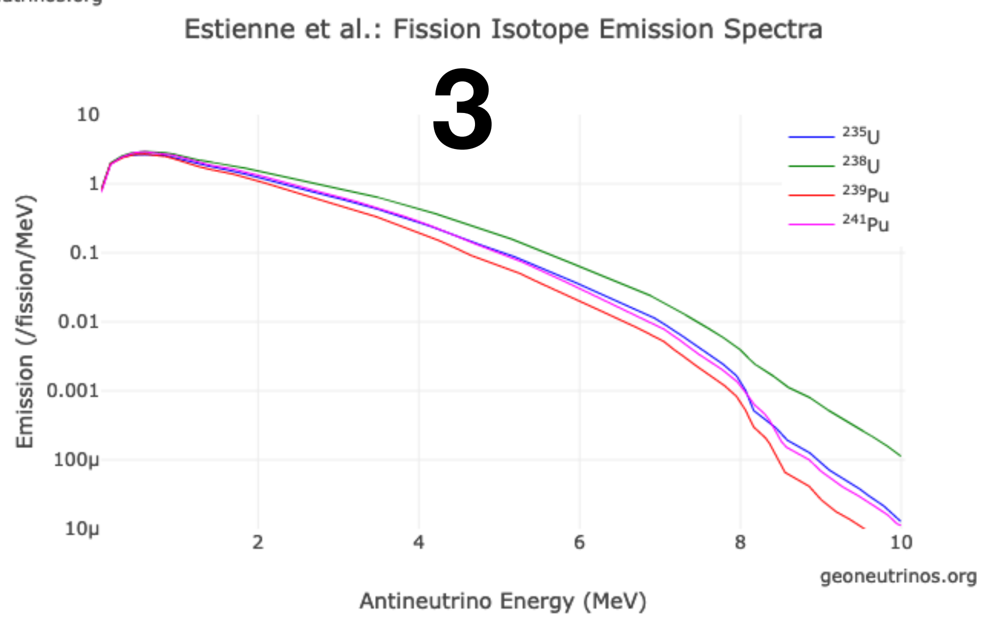


Linear interpolation between data points w/ 10 keV bins

0-10 MeV

^{235}U, ^{238}U, ^{239}Pu, ^{241}Pu Estienne et al. (2019)





2-8 MeV

^{239}Pu, ^{241}Pu Huber (2011)

^{235}U, ^{238}U Kopeikin et al. (2021)

0-2, 8-10 MeV

Estienne et al. (2019)

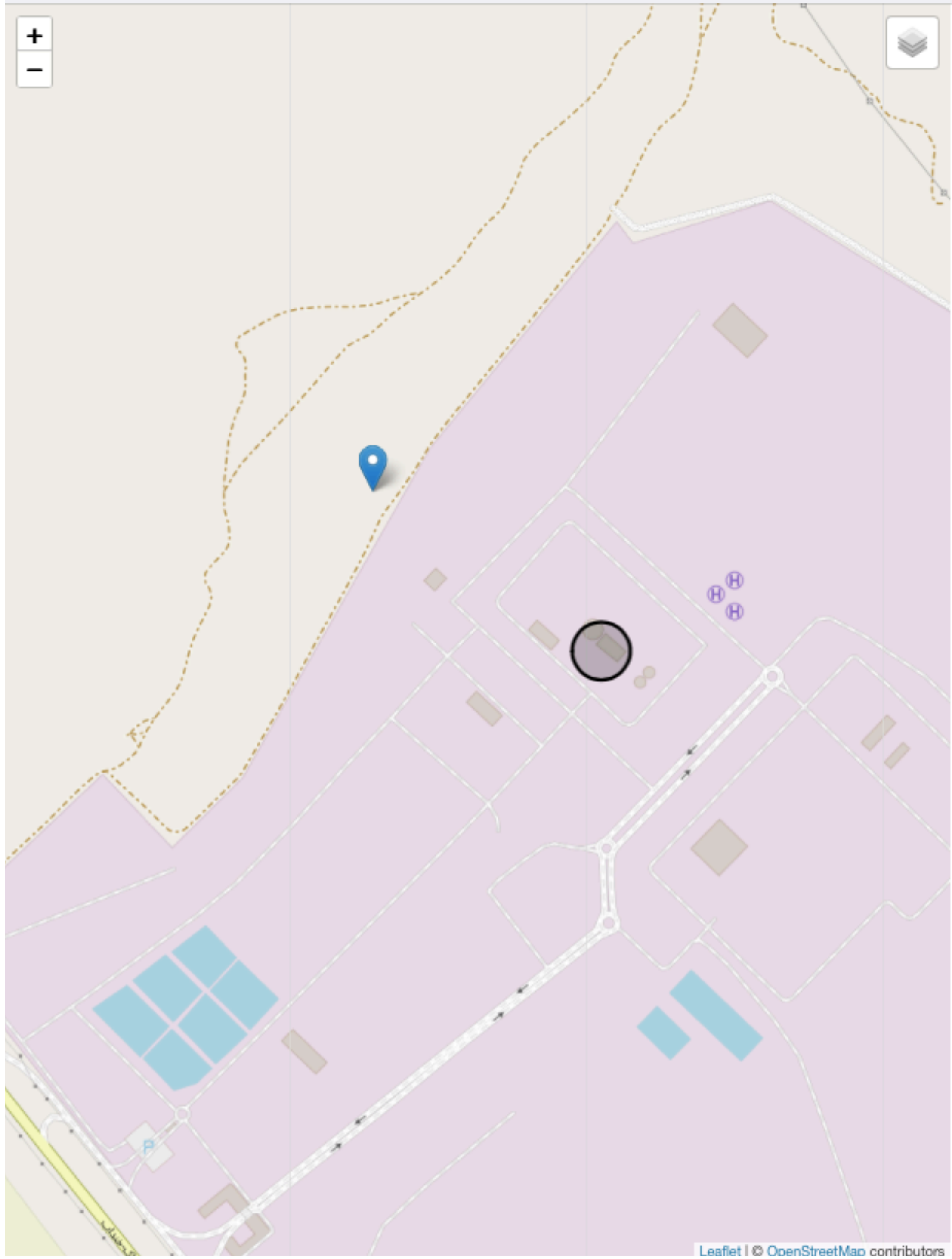
2-8 MeV

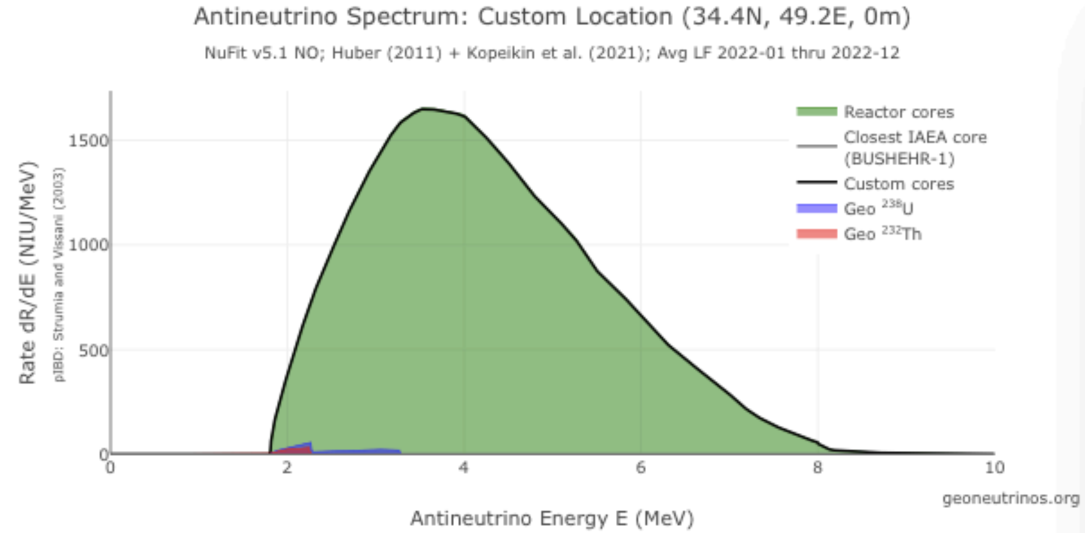
^{235}U, ^{239}Pu, ^{241}Pu Huber (2011)

^{238}U Mueller et al. (2011)

0-2, 8-10 MeV

Estienne et al. (2019)





Detector | Reactors | GeoNu | SnNu | SolarNu | Direction | pIBD/eES | NuOsc | Muon | Output | About

Spectrum Stats- pIBD: Strumia and Vissani (2003)

R_{total} = 5558.1 ± 92.7 NIU

- 1 NIU (Neutrino Interaction Unit) = 1 interaction/10^{32} targets/year
- Uncertainty shown obtains from the reactor and geo-neutrino signal uncertainties added in quadrature

IAEA Cores- Huber (2011) + Kopeikin et al. (2021); Avg LF 2022-01 thru 2022-12

R_{reac} = 14.1 ± 0.4 NIU

$R_{closest}$ = 1.4 ± 0.0 NIU (10% of R_{reac})

$D_{closest}$ = 634 km (BUSHEHR-1 elevation -8.7 m)

Custom Cores

R_{custom} = 5498.1 ± 91.6 NIU

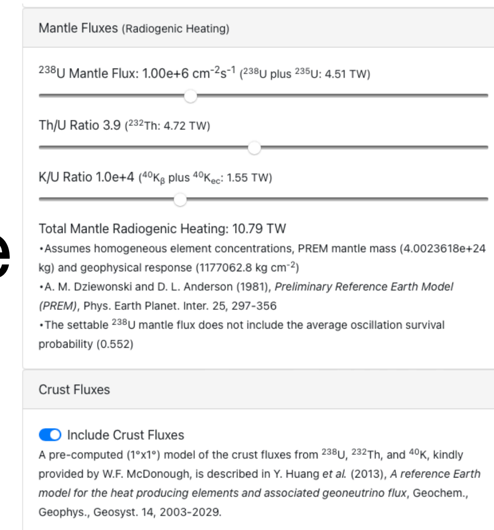
$R_{closest}$ = 5498.1 ± 91.6 NIU (100% of R_{reac} + R_{custom})

$D_{closest}$ = 1.81 km (Arak IR-40 elevation 1750 m)

- Monthly load factors since 2020 from IAEA-Power Reactor Information System (PRIS)
- 2022 load factors for reactor cores in Ukraine not reported and arbitrarily set to 0
- Uncertainties shown derive solely from the isotope emission spectra
- Elevation is height above the WGS84 reference ellipsoid

Geo-neutrinos

- Pre-calculated crust signal on 1° x 1° grid (On/Off switch)

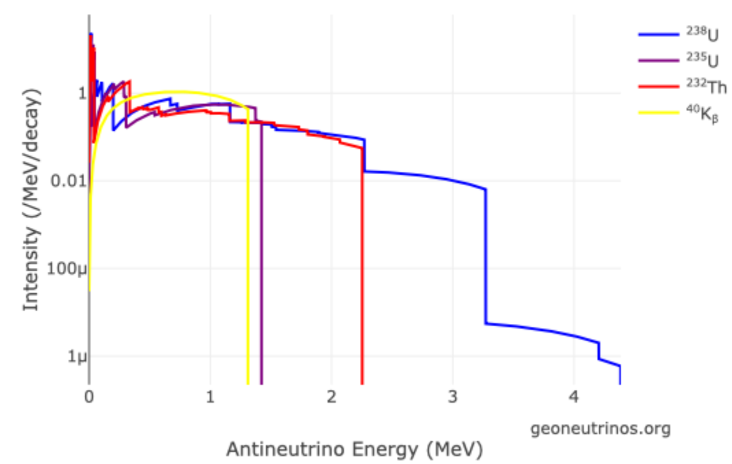


- User-defined uniform mantle signal
  - keyed to flux from ^{238}U + Th/U + K/U- all setable
  - associated mantle radiogenic heating

- Average oscillation survival probability

- U, Th, K spectra from Enomoto

- Include guesses for uncertainties



Comments & Suggestions ?

- Discussions, Q&A here at AAP 2023
- Email to sdye@hawaii.edu and abarna@hawaii.edu
- Submit to https://github.com/geoneutrinos/reactors/issues

Referencing

Please cite this website when using the results of this model in research papers and/or presentations:

A.M. Barna and S.T. Dye (est. 2010). *Antineutrino Model* https://reactors.geoneutrinos.org. Accessed DAY MONTH YEAR

Documentation is online

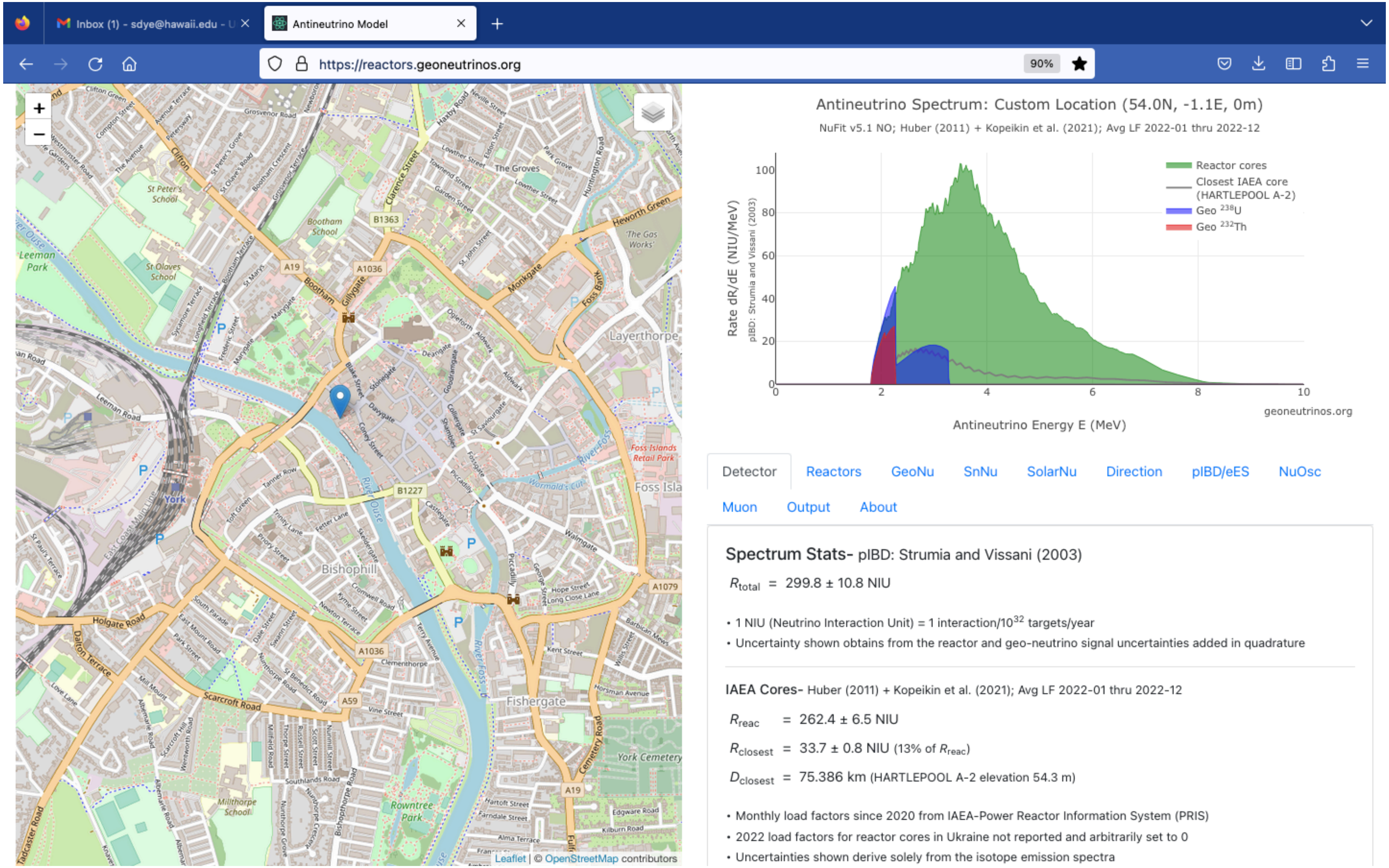
(please refrain from citing old paper on arXiv; it is outdated)

Shout out for Support

- **NSF 2009** Education and outreach for *CSEDI Collaborative Research: Neutrino Geophysics: collaboration between geology and particle physics* (award # 0855838)

- **NSF 2011** Education and outreach for *Collaborative Research: Estimating the mantle contribution to the Geo-neutrino flux at the Sudbury Neutrino Observatory* (award # 1068097)

- **LLNL 2012 - 2023** Neutrino signal estimates for *Remote Discovery and Monitoring of Small Reactors* (various subcontracts)



Inbox (1) - sdye@hawaii.edu - U
Antineutrino Model
https://reactors.geoneutrinos.org
90%
Leaflet | © OpenStreetMap contributors
Antineutrino Spectrum: Custom Location (54.0N, -1.1E, 0m)
NuFit v5.1 NO; Huber (2011) + Kopeikin et al. (2021); Avg LF 2022-01 thru 2022-12
Reactor cores
Closest IAEA core (HARTLEPOOL A-2)
Geo 238U
Geo 232Th
Rate dR/dE (NIU/MeV)
pIBD: Strumia and Vissani (2003)
Antineutrino Energy E (MeV)
geoneutrinos.org
Detector
Reactors
GeoNu
SnNu
SolarNu
Direction
pIBD/eES
NuOsc
Muon
Output
About
Spectrum Stats- pIBD: Strumia and Vissani (2003)
R_total = 299.8 ± 10.8 NIU
• 1 NIU (Neutrino Interaction Unit) = 1 interaction/10^32 targets/year
• Uncertainty shown obtains from the reactor and geo-neutrino signal uncertainties added in quadrature
IAEA Cores- Huber (2011) + Kopeikin et al. (2021); Avg LF 2022-01 thru 2022-12
R_reac = 262.4 ± 6.5 NIU
R_closest = 33.7 ± 0.8 NIU (13% of R_reac)
D_closest = 75.386 km (HARTLEPOOL A-2 elevation 54.3 m)
• Monthly load factors since 2020 from IAEA-Power Reactor Information System (PRIS)
• 2022 load factors for reactor cores in Ukraine not reported and arbitrarily set to 0
• Uncertainties shown derive solely from the isotope emission spectra