Predictive Modeling of Terrestrial Radiation Exposure from Geologic Materials

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DOE/NV/25946--2303

Introduction

• Aerial gamma ray surveys are important for those working in nuclear security and industry for determining locations of both anthropogenic radiological sources and natural occurrences of radionuclides.

• During an aerial gamma ray survey, a low flying aircraft, such as a helicopter, flies in a linear pattern across the survey area while measuring the gamma emissions with a sodium iodide (NaI) detector.

• Currently, if a gamma ray survey is being flown in an area, the only way to correct for geologic sources of gamma rays is to have flown the area previously (Dickson and Scott 1997). This is prohibitively expensive and would require complete national coverage.

• This project's goal is to model the geologic contribution to radiological backgrounds using:
-Published geochemical data
-Geologic data
-GIS software
-Remote sensing

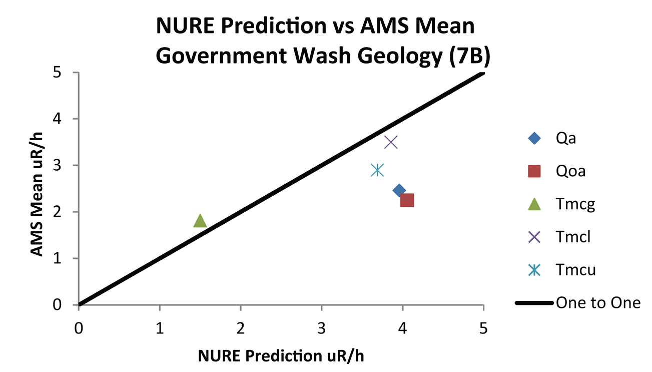
• K, U and Th are the three major gamma emitters in geologic material. U and Th are assumed to be in secular equilibrium with their daughter isotopes.

• If K, U, and Th abundance values are known for a given geologic unit the expected gamma ray exposure rate can be calculated using the Grasty equation (equation 1) or by modeling software.

Figure 1:
National Security Technologies, LLC. (NSTec) helicopter with sodium iodide (NaI) detector flying over the Lake Mohave field area

Figure 2:
NSTec helicopter over NSTec/UNLV field team

Models



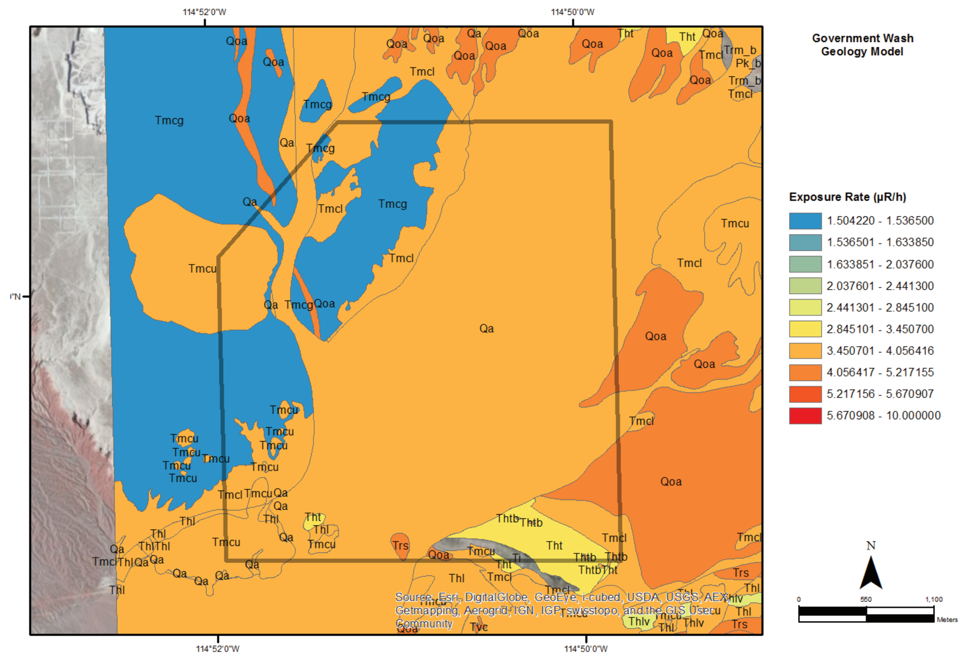
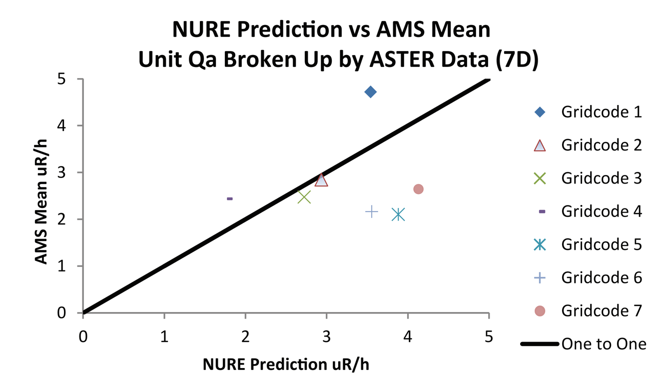


Figure 5A:
This model, of our field area Government Wash, uses the geologic map published by the Nevada Bureau of Mines and Geology to define geospatial areas. NURE data is assigned to each unit based on location and an exposure rate is calculated using the Grasty Equation. The plot above shows the relationship between our prediction and the aerial survey.



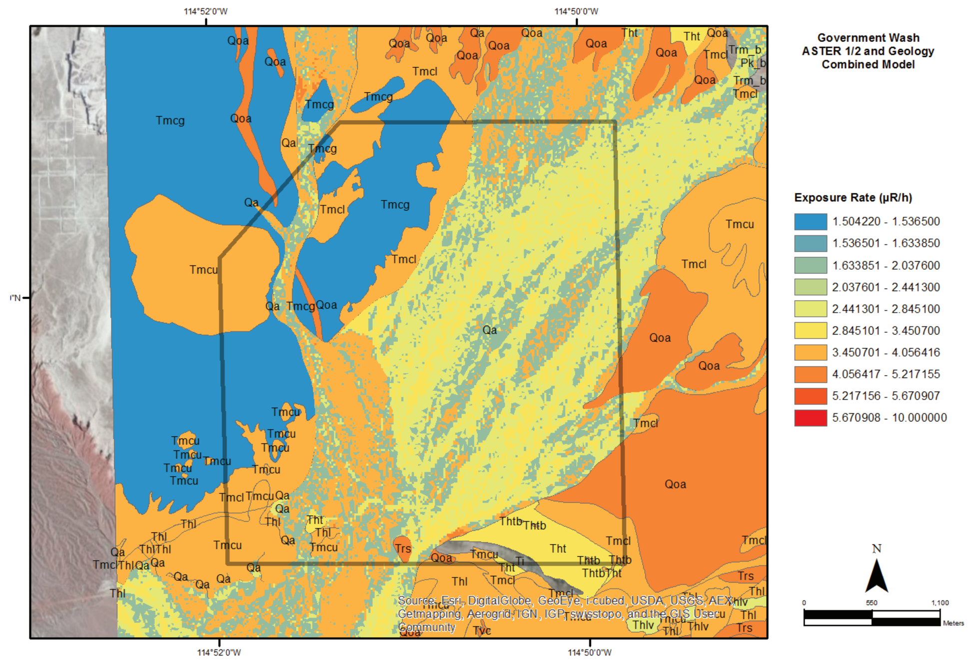


Figure 5B:
This model of Government Wash uses the same geolgic map as 5A and ASTER band ratio of 1/2 to track the distribution of ferric iron and break up the alluvial fan (Qa). NURE data is assigned to each unit based on location and an exposure rate is calculated using the Grasty Equation. The plot above shows the relationship between our prediction and the aerial survey in the broken up alluvial fan.

Results

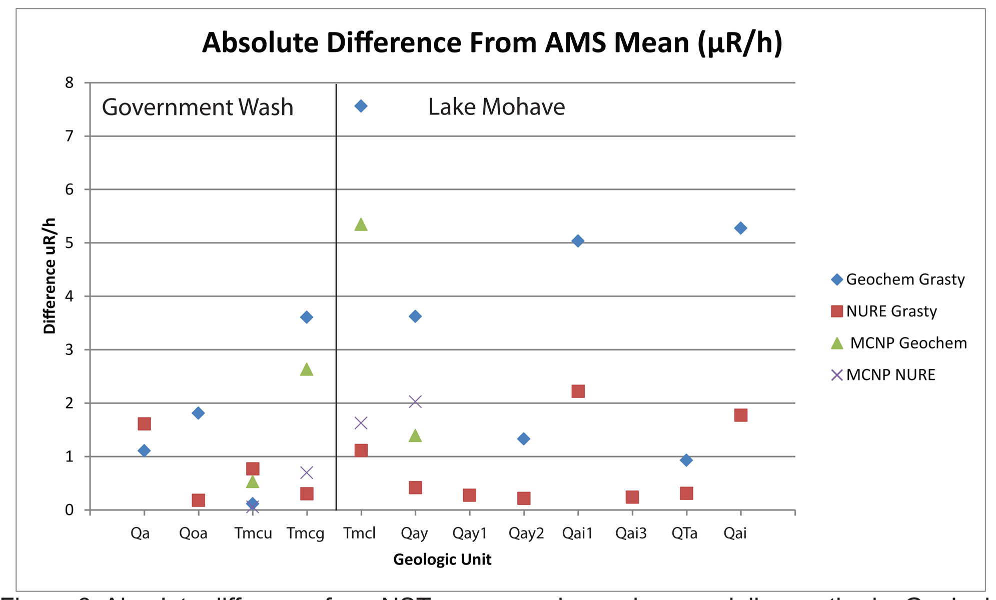


Figure 6: Absolute difference from NSTec mean using various modeling methods. Geologic units are from both Government Wash (Qa-Tmcl) and Lake Mohave (Qay-Qai).

Future Work

•We will create generic MCNP models for endmember rocks that will be applipicable to all rocks of that type.

•This will allow us to compare the screening properties of each rock type.

•22 soil samples have been collected at Lake Mohave and Government Wash
•At many of these sampling points we have:
Gamma spectrometry on soil samples
HPGe data
Aerial survey
Pressurized Ion Chamber measurements
•We will also be performing ICP-MS on the soil samples
•Using these data we intend to find a factor to reconsile the differences in the two datasets so they are equally usable

Methods

Sources of Data

• Preexisting geochemical data has been collected for the two study areas, Government Wash and Lake Mohave, from the following national databases: National Uranium Resource Evaluation (NURE), Geochemistry of Rocks of the Oceans and Continents (GeoRoc) and Integrated Earth Data Applications (IEDA).

• NURE low resolution aerial gamma ray survey with national coverage of the distribution of uranium, thorium and potassium from spectra.

• January 2014 there was a combined field survey including individuals from UNLV, NSTec and the Geologic Survey of Canada (GSC), at both Lake Mohave and Government Wash. Soil samples were taken in every geologic unit while CGS and NSTec conducted ground and aerial surveys using sodium iodide (NaI) and high purity germanium (HPGe) detectors respectively.

Defining Geospatial Areas

•Geologic maps organize geospatial areas into geologic units, typically based on rock type, but may not capture the natural variations in K, U and Th

• Instruments such as the Advanced Space-borne Thermal Emission and Reflection Radiometer (ASTER) is an orbital instrument which is capable of collecting data across bands of the electromagnetic spectrum. Different mineral suites are detectable using different band combinations.

•These data can be used to assign geochemical or NURE data to geospatial regions that exhibit similar minerologies.

Modeling Technique

• The primary modeling technique is to assign geochemical and NURE survey data to the unit it occurs in, and through statistical analysis, obtain a representative K, U and Th value for each unit.

• Using the Grasty equation (equation 1), an exposure rate can be calculated based on the geochemical or NURE survey data (Grasty et al., 1984).

Equation 1:
$$E=1.32*K+ 0.548*eU + 0.272*eTh$$
Experimentally derived equation that takes known concentration of potassium (K), uranium (eU), and thorium (eTh) and returns an exposure rate in uR/h (Grasty et al., 1984)

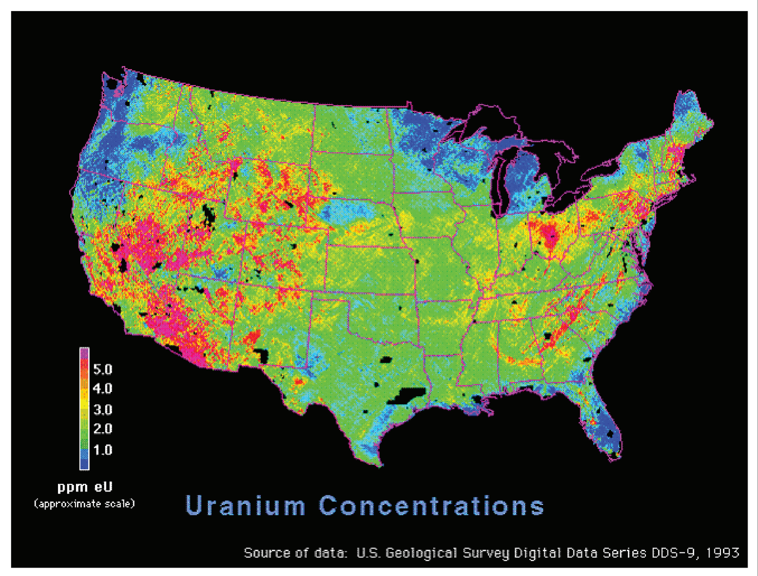


Figure 3:
National map showing U concentration in soil and rock derived from NURE survey data

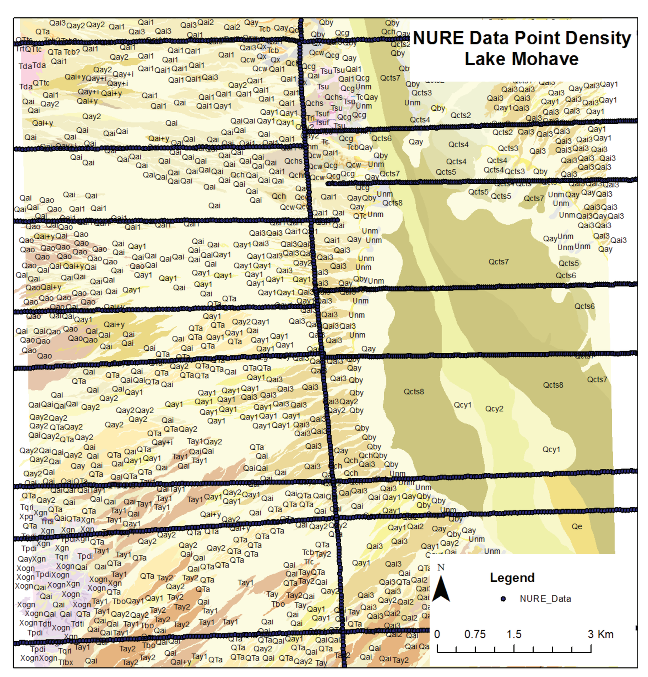


Figure 4:
NURE data point density at Lake Mohave overlain onto the geologic map

Monte Carlo N-Particle Transport

Monte Carlo N-Particle Transport software (MCNP), developed by Los Alamos National Laboratory, is modeling software designed to simulate particles and their interactions with matter. Using this software, models have been created that represent various lithologies. These simulations randomly generate gamma ray photons at energy levels expected from natural radiologic sources.

The photons take a random path through the simulated geologic media and deposit their energy at the end of their track. A series of nested spheres have been created and filled with simulated atmosphere to record energy deposition. Energies deposited are binned in the same manner as the NaI detectors used during an aerial survey. These models are used in place of the simplistic Grasty equation as it takes into account absorption properties of the lithology which the simplistic equation ignores.

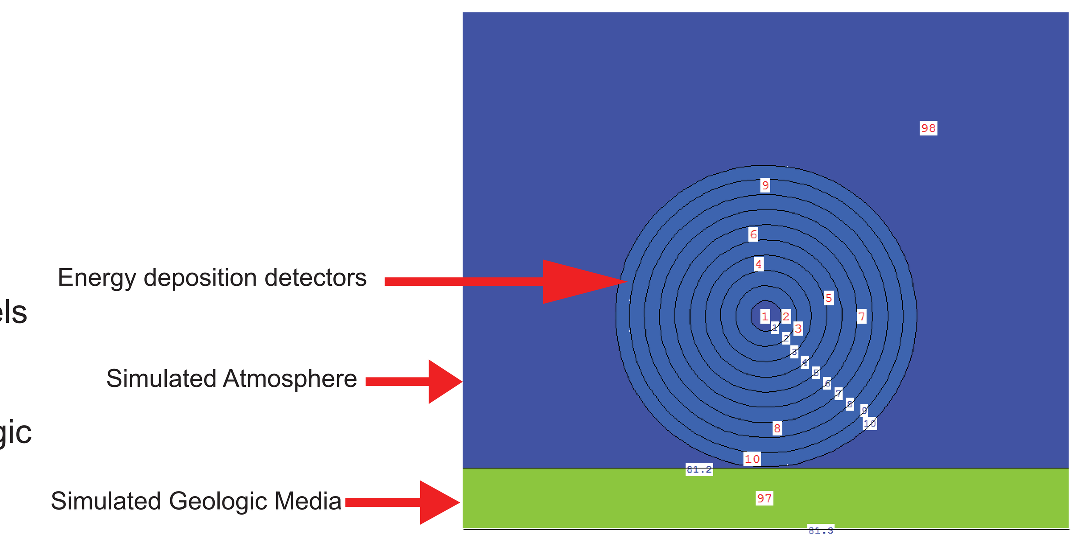


Figure 7: An x/z cross section of our generic model. 97 is our defined "unit" based on chemistry input. 98 is simply atmosphere above the geology. The series of nested spheres are filled with atmosphere and count energy deposition within them.

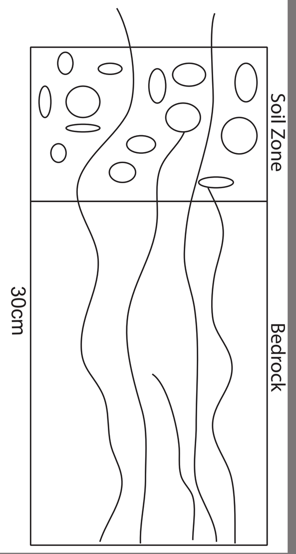


Figure 8: A representation of a photons path through geologic media. Some photons escape the subsurface and become detectable. Many others interact with materials in the subsurface and are not detectable by survey equipment.

Acknowledgements

I would like to thank NSTec for providing funding for this project; Dr. Ralf Sudowe for his insight into terrestial radiation and Dr. James Faulds for providing GIS data in the Lake Mohave area.

UNLV HiPSEC:
This research was sponsored (or sponsored in part) by the National Nuclear Security Administration under the Stewardship Science Academic Alliances program through DOE Cooperative Agreement #DE-NA0001982.

This work was done by National Security Technologies, LLC, under Contract No. DE-AC52-06NA25946 with the U.S. Department of Energy and supported by the Site-Directed Research and Development Program.

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