GEONEUTRINO RADIOMETRIC ANALYSIS FOR GEOSCIENCES (GRAFG) AT DUSEL HOMESTAKE, SOUTH DAKOTA
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Abstract

Neutrino detection is a mature area of research, which is rapidly developing in the area of particle physics to improve detection sensitivities and optimization for specific applications. Large-scale detectors (meaning kilo-ton or more in size) were designed and built to study particle physics properties and solar neutrinos. Recently a 1-ton detector was optimized for detecting the antineutrinos from a power reactor. Directionality in the detection of the neutrinos was exploited in Cerenkov detectors. In this context it was realized the 1-ton detector is competitive and mobile for certain applications in geosciences.

The cost of building large detectors is in the range of few hundred millions dollars. The 1-ton detector can be built for under10 million dollars. A fully tested and used detector may be available for immediate research and development purposes in geosciences.

Our goal is to develop a radiometric method using antineutrinos from the Earth for in-situ determination of the heat producing elements (HPE) in regions inaccessible to conventional sampling techniques. We also want to investigate correlations with HPE in different geothermal regions.

INTERESTED PRINCIPALS, COLLABORATORS AND OTHERS

Working Group Members:

- Group Leader and Low Radioactivity Measurement of HPE: Dr. P. Ila,
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- Heat Flow/Geophysics: Prof. W. Gosnold,
  Geology and Geological Engineering Dept.,
  Grand Forks, University of North Dakota, ND

- Cosmic-ray Physics: Prof. G. I. Lykken,
  Physics Dept. Grand Forks, University of North Dakota, ND

- Antineutrino detector instrumentation: Dr. P. Jagam,
  Physics Dept., University of Guelph;
  The NORM Group Organization, Guelph, ON, Canada

- Educational Outreach:
  1. Prof. M. McCurry,
     Rural Sociology Dept., South Dakota State University (SDSU),
     Brookings, SD.
  2. Mr. D. Oedekoeven,
     SDSU West River Agricultural Center, SD.
  3. Mr. S. A. Ternes, Grand Forks Public Schools, Grand Forks, ND.
  4. AISES - American Indians in Science and Engineering Society.
  5. Ms. B. Lutekin, Media Designer, Arlington, MA

Group Members:

- Geochemistry: Prof. F. Frey, Earth Atmospheric and Planetary Sciences Dept.,
  Massachusetts Institute of Technology, Cambridge, MA

- Bulk Silicate Earth Model:
  Prof. W. F. McDonough, Geology Dept., Univ. of Maryland, College Park, MD

- Solid angle analysis and shielding design:Prof. R. Pevey,
  Nuclear Engineering Dept., Univ. of Tennessee, Knoxville, TN

- Antineutrino large detector instrumentation:
  Dr. N. Tolich, Physics Dept., Univ. of Washington, WA

Interested Others:

- Antineutrino Detector Physics: Prof. J. Formaggio,
  Physics Dept., Massachusetts Institute of Technology, Cambridge, MA

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1. SCIENCE

1.1. INTRODUCTION

Geoneutrinos are the electron antineutrinos produced during the negative beta-decay of primordial radioactive isotopes and in the fission products of the long lived radioisotopes in the Earth. Geoneutrino detection technology is rapidly evolving to probe the Earth's interior, because geoneutrinos have penetration capability of the entire Earth. It is this property of the geoneutrinos, which makes it possible to probe the deep interior regions of the earth which are otherwise inaccessible by conventional sampling methods by drill core retrieval. The regions of the Earth are shown in Figure 1.

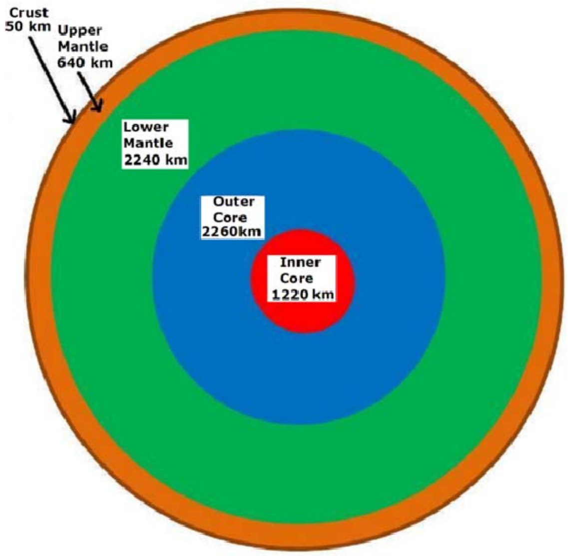

Figure 1. Cross-sectional view of the interior regions of the Earth based on Anderson (2007) [1]. The radial thicknesses of the different regions are labeled in the figure. Compared to the total radius of 6370 km of the Earth, the deepest drill cores were obtained from a maximum depth of only 10 km from the surface of the Earth. The inner core of the Earth is totally inaccessible for sampling by drilling methods. Volcanoes to some extent provide access to the upper mantle.

Currently, there is increased interest world-wide [2-10] to use geoneutrinos to probe the Earth's deep interior for investigating the concentrations of the radiogenic heat producing elements (HPE) K, Th and U in the Earth. This investigation provides answers to the unresolved issues facing the geosciences community. The three main unresolved issues are discussed in sections 1.1.1, 1.1.2 and 1.1.3.

1.1.1 Geochemistry - The Bulk Silicate Earth (BSE) paradigm:

Concentrations of CI chondritic meteorites are thought to be representative of primitive concentrations of the solar system. Earth's global composition is generally estimated from that of CI by using geochemical principles which account for loss and fractionation during planet formation. Bulk Silicate Earth (BSE) means present crust plus mantle. BSE describes the primitive mantle subsequent to core formation prior to the differentiation between crust and mantle. BSE estimates of K, Th, U abundances in the crust and upper mantle [11, 12] are based on geochemical models [13, 14, 15].

BSE Paradigm: Estimated total radiogenic heat of the Earth from the BSE is about 19 TW which is about half of the total terrestrial heat flow estimated from the geophysical studies.

The abundances of K, Th, U of the core and lower mantle are not established because of the inaccessibility of these regions for sample collection for analysis.

Geoneutrinos not only originate from the heat producing elements in the different regions of the Earth, but are also available at the surface of the Earth because of their high penetration capability. This penetration capability makes it possible to probe the deep interiors of the Earth, thus providing direct measurements to determine the abundances of the K, Th, U in different regions of the Earth.

1.1.2 Geophysics – Terrestrial Heat Flux

Estimates of Earth's surface heat flux range from 30 TW, based on observed heat flow, to 44 TW using heat conduction models based on assumptions of oceanic lithosphere thickness and basal temperature. A combination of several sources including: radiogenic heating, processes of mantle and core formation and differentiation, delayed radiogenic heating, earthquakes, and tidal friction account for the surface heat flux. The single largest component is estimated to be 28 TW due to radiogenic heating from K, Th, and U based on the BSE model. The distribution of heat producing elements (HPE) throughout the crust, mantle and core is poorly understood, and estimates of non-radiogenic sources, particularly heat flow in ocean basins, have become controversial. **The range of heat flux estimates and the BSE model for HPE have led some to suggest that there is either a good match between heat flow and heat production or there is deficit or excess of heat flow** [16 - 20].

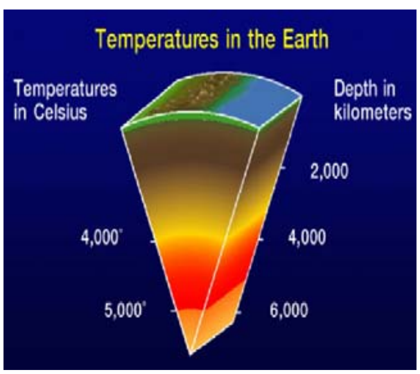

Figure 2. Geothermal Education Office, Tiburon CA representation of the variation of temperatures with depth in the interior regions of the Earth. 83% of present surface heat flow is due to radioactive decay of K, Th and U. Earth's mantle is cooling at a rate of 36° C Ga^{-1}.
Heat sources in the deep interior of the Earth are debated.

1.1.3 Geochemistry - K, Th and U in the core of the Earth:

In this context, it is worth noting that several attempts were made to account for radiogenic heat producing elements in the core [21, 22]. The suggestion that there is a large amount of uranium in the inner core of the Earth is totally unacceptable from high temperature geochemistry point of view [13, 22 -24] because uranium and thorium are not siderophile elements. Siderophile elements form compounds or alloys with iron.

1.1.4 Limitations of geoneutrino detection (by majority of existing/planned detectors)

- The large monolithic neutrino detectors built so far were designed and operated for solving problems **other than [25]** the geoneutrino studies except KamLand.
- The large-scale detectors built for particle physics research were **not optimized** to detect geoneutrinos.
- The detectors based on the principle of detecting neutrinos by inverse beta-decay **suffer** from threshold energy constraints for the detection of geoneutrinos [26-29].
- They do **not detect a major fraction** of the emitted intensity in the spectral distribution of the geoneutrinos.
- The detectors which use scintillation techniques **suffer from loss of directionality** of the neutrino interaction in the detecting medium.
- They **cannot provide information** to assign the measured values to corresponding regions of the Earth's interior.

1.1.5 Proposed analytical approach: Geoneutrino Radiometric Analysis For Geosciences

The differences in the model calculations and the limitations of the detectors built to date demand that the experimental techniques to measure the total HPE content in all regions of the Earth be optimized for detecting the entire geoneutrino spectrum of energies with directional sensitivity as to the origin of the geoneutrinos. Leading scientists like De Meijer [8]. Winter [30], Fields and Hochmuth [31], Batygov [32] are emphasizing the importance of developing the technology for directional sensitivity and radial angular measurement in geoneutrino studies. We are proposing to develop the methodology addressing those needs.

There are two properties of geoneutrinos which are useful for detection.

1) Geoneutrinos penetration capability of the entire thickness of the Earth mostly undetected, is useful to assay the entire Earth.

2) Geoneutrinos travel in straight lines from the point of origin, providing the directionality. For example, neutrons do not travel in straight lines from point A to B.

Our proposed approach of Geoneutrino Radiometric Analysis For Geosciences puts the above two properties for that same purpose.

We propose dividing the field of view of the detector into cones enclosing the regions of the Earth as shown in the schematic, it can be seen that the differential regions enclose different combinations of the contributions of the neutrino origins.

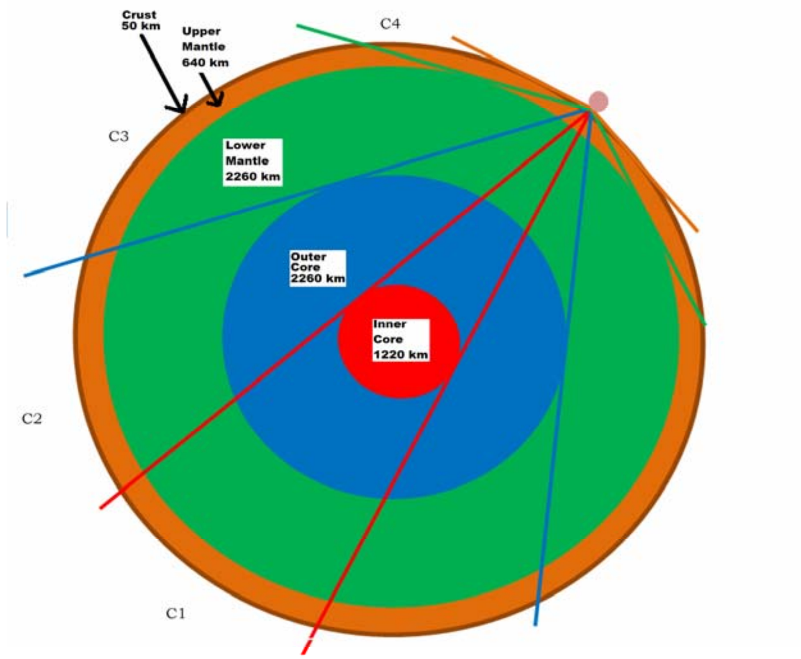

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Figure 3. Cross-sectional schematic of the conical field of view dividing the interior regions of the Earth from the detection point of view. The figure provides cross sectional view of the cones which completely enclose the inner core, outer core, lower mantle, upper mantle regions in the interior of the Earth.

We propose to design a detector optimized to detect the entire geoneutrino spectrum and to provide directional information to separate the contributions from the different regions of the interior of the Earth. The optimization of the energy threshold for the detection of the geoneutrinos will be based on the spectrum shapes reported for the beta-decaying primordial radioactive isotopes [33]. Our goal is to include the entire energy spectrum of the geoneutrinos into the detection mechanism.

We propose to design to optimize the counting efficiency of the detector such that it would be possible with the optimized detector to separate the contributions of the interior regions of the Earth as shown in Figure 3.

We also propose to design our detector with spectrometric capability to resolve the measured geoneutrino spectra into their component primordial activities. This capability will determine the concentrations of the individual HPE elements. The precision of determination will be optimized as required.

The design of our detector has evolved from the results reported by the various particle physics detectors already built and from the results reported for the application developed for the purpose of monitoring the Comprehensive Test Ban Treaty (CTBT) [34, 35]. The proposed detector will make a unique contribution to the study of the geoneutrinos from the Earth as a whole. The electron scattering interaction [36] of the geoneutrinos will allow a measurement of the energy spectrum and the directional information necessary to the identification of the contributions from the different regions of the Earth.

The counts in each cone C1, C2, C3, C4 in Figure 3 are proportional to the radioactivity in that cone. The component contributions in each cone have to be resolved from the observed total counts in each cone region projected on the surface of the upper half of a spherical detector.

The counts in the lower half of the spherical detector viewing the cones may be used for determining the background diffuse radiation. This principle was demonstrated in the MUNU (mewnew) [37] Bugey Reactor experiment. The engineering costs of the detector and the associated electronics will be included in the S-4 proposal while the experimental costs will be included in the ISE costs.

1.2 OBJECTIVES

Employ a cubic meter size mobile antineutrino detector.

1. Develop a radiometric method using antineutrinos from the Earth for in-situ determination of HPE to demonstrate proof-of-concept.
2. Optimize the antineutrino radiometric method to determine HPE in regions inaccessible to conventional sampling methods
3. Apply the method to investigate correlations with HPE in different geothermal regions. (Discussions are ongoing).
4. Interface with high temperature geochemistry knowledge base regarding fractionation of HPE in Earth's interior (Discussions are ongoing).
5. Refine the BSE model. (Discussions are ongoing).

1.3 APPROACH TO ACHIEVE THE OBJECTIVES

List of topics for objective 1:

1. Investigate solid angle dependence
2. Investigate backgrounds and interferences
3. Design geoscience goals for instrumentation
3. Investigate Proof-of-concept (POC)
4. Test the POC and draw conclusions
5. Optimize and iterate item 2 and 3 for depth sensitivity

List of topics for objective 2:

1. Investigate calibration of the method for HPE
2. Investigate precision of the method
3. Investigate accuracy of the method

List of topics for objectives 3, 4, 5: Discussions are ongoing.

How the list of topics are amalgamated into a program to address the objectives:

We have listed above the series of investigations and experiments, needed to be done to achieve the science objectives.They are listed in the order in which they are needed for a logical progression of steps to achieve the science goals.
As can be seen from the steps listed for objectives 1 and 2, to do the whole Earth assay of the primary Heat Producing Elements (HPE) we need instruments capable of in-situ measurements as opposed to grab sampling or time consuming and expensive drill core sampling methods.

1.4 EXPECTED RESULTS

1. Well tested instrumentation and methodology for geoneutrino radiometric analysis of heat producing elements into the deep interior of the Earth.
2. Synergy with particle physics groups is expected to produce radiometric analysis to the center of the Earth.

1.5 SIGNIFICANCE OF RESULTS

1. The expected results are supposed to show whether there is radioactivity in the core of the Earth by different methodology independently.
2. In comparison with large detector proposals for investigating the radioactivity in the deep interior of the earth, the significance of our proposal is that the results are achieved in a shorter time and at a less cost. The larger detectors can improve the precision investing 5 times the time required getting the results by us and at 10 times the cost.
3. Groups who worked or working with larger detectors are recommending directional sensitivity. By our project we can provide a head start in that direction.
4. We are proposing to adapt the existing small detector technology developed for the purpose monitoring the reactor antineutrinos to the purpose of geoscientific studies of the HPE of the mantle and core.
5. We are not replicating the monolithic detector technology. We are developing a technology and methodology to be of complimentary value.

1.6 WHY IMPORTANT TO DUSEL AT HOMESTAKE?

1.6.1 Cosmic-ray shielding

Geoneutrino radiation field is of interest for measuring the HPE composition of the Earth’s interior regions. However, this radiation field of interest is part of many other radiation fields such as cosmic rays, gamma rays and neutrons which can interact with the medium of the detector and produce signals comparable to the geoneutrino signals. These interfering radiation fields called “backgrounds” have to be minimized or eliminated to get the best signal to background ratio.

The location of the geoneutrino detection is, therefore, influenced by considerations to optimize the required shielding against these interfering radiations. The penetrating component of the Cosmic rays can only be shielded by going to underground locations. The variation of cosmic-ray intensity with depth is shown in figure 3. It can be seen from the figure that Homestake is a deeper location than the WIPP and Soudan locations in the continental United States. The medium level DUSEL at a depth of 4850 feet is therefore favorable at Homestake.

In addition, the bedrock geology indicates that this location is in amphibolite structures which are low in HPE than other hard rock mine locations like Soudan, even though not as low as in the WIPP location. This is an added advantage at Homestake in terms of the shielding requirements against gamma rays and neutrons in the ambient environment.

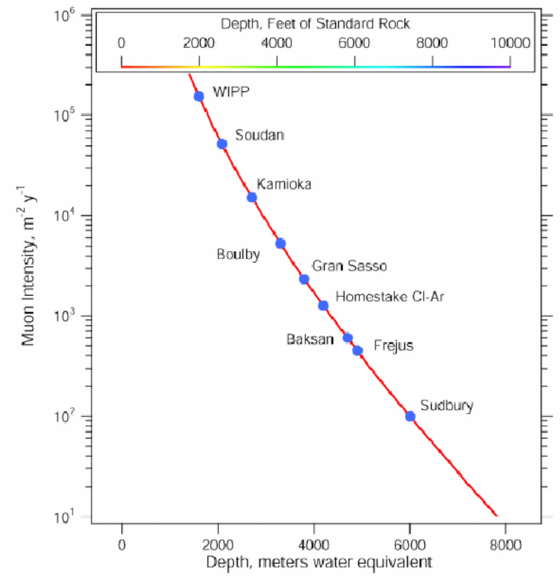

Figure 4. Variation of cosmic-ray muon intensity with depth. Homestake location offers greater shielding against cosmic-ray muons than WIPP and Soudan in continental United States. Except at WIPP, HPE abundances in the rock are low at Homestake than other locations.

1.6.2 Importance to the International Geophysics community:

Testing of post-glacial warming magnitude at strategically located periglacial region of Homestake in South Dakota:

We propose to use the DUSEL site in South Dakota as part of a critical test of a recently proposed hypothesis that the amplitude of post-glacial warming in northern high latitude regions may be of the order of 10 to 15 °C rather than 3 °C as is commonly thought. If the hypothesis is correct, some northern hemisphere heat flow values may require revision by as much as 40 percent and our estimate of total global heat flux could require significant upward revision. The principal evidence for this new hypothesis is that ensembles of heat flow determinations in parts of Europe and North America show a systematic increase in heat flow with depth. These observations are predominantly from ensembles of heat flow determinations at different depths in different boreholes and to a minor degree from analyses of heat flow variation in individual boreholes. In Europe, the increase in heat flow with depth has been observed by analysis of more than 1500 deep boreholes located throughout the Fennoscandian Shield, East European Platform, Danish Basin, Germany, Czech Republic, and Poland. There are significantly fewer deep boreholes in North America, but an increase in heat flow with depth appears in a statistical analysis of a suite of 759 sites in the IHFC Global Heat Flow Database for the region east of the Rocky Mountains and north of latitude 40 °N. However, no existing sites provide the critical information necessary to accurately determine whether heat flow increases with depth. The critical data are accurate temperature vs. depth measurements in boreholes or in deep underground sites where samples for thermal conductivity analyses are also available. The

DUSEL site in South Dakota has the capability to provide precisely the necessary data and access to samples and it is strategically located in the periglacial region where we expect the signal to be detectable.

1.6.3 Effect on international efforts or studies:

1. There is strong contribution by the geophysical study of post glacial warming magnitude to the international studies.
2. International scientists like Fiorentini and Mantovani [10] are emphasizing the importance of HPE local variation studies.
3. Leading scientists like De Meijer [8], Fields and Hochmuth [29], Batygov [30] are emphasizing the importance of directional sensitivity for the geoneutrino detector.

We are proposing the geoneutrino radiometric analysis directional sensitivity by cost effective Cerenkov detection methodology.

1.6.4 Appropriateness for inclusion in the envisioned facility and ISE:

Geoneutrino studies are envisioned in NUSEL, DUSEL as can be seen from DUSEL PAC Report 2006. The present proposal is a continuation of these efforts with a cost effective small detector adapted to develop a general purpose radiometric methodology.

1.6.5. Why now as opposed to other approaches?

There may be a practical window of opportunity within which to carry out the experiment or at least to get started to engineer the optimized detector. The 1-ton detector designed and tested [27] for CTBT applications may be available in the next six months for further tests in the context of detecting geoneutrinos.

We propose to understand the backgrounds representing part of the geoneutrino spectrum including fission neutrinos in the energy region from 2 MeV - 10 MeV and up to 20 MeV. Thus if prompt approval is given for our proposal and if the construction is kept to the engineering schedule of two years the cost of engineering design can be minimized, and the initial suite of experiments can be started as proposed.

1.7 WHY IMPROTANT TO NSF?

The proposed geoneutrino radiometric analysis for geosciences (GRAFG) techniques and methodologies will open new opportunities for growth and diversity promoting inter disciplinary research among the disciplines of Geology, Geochemistry and Geophysics. This proposal also promotes inter agency partnerships among academic and national institutions.

So far most of the geoneutrino detectors, running or proposed, are using mostly the inverse beta decay methodology to make neutrino flux measurements for research in particle astrophysics. We are proposing to adapt the hardware techniques developed so far and integrate them with the Elastic scattering detection methodology.

There is risk involved in this approach because it is not as well tested as the other methodology in many different contexts. It is well worth taking this risk to obtain directional information about the originating region in the interior of the Earth.

By tasking this risk with the proposed small detector, this proposal integrates the technology developed by the national institutions for some other application with the needs of the academic community in geosciences.

We propose that the geoneutrino radiometric analysis for geosciences (GRAFG) techniques and methodology be developed further as part of a national facility under DUSEL for more detailed radiometric mapping of the interior regions of the Earth with focus on geothermal energy exploration and uranium exploration. Not only is this approach appropriate for NSF to support but also in developing this methodology NSF will be building a laboratory infrastructure in which other experiments could be carried out. To achieve all this we need to do engineering studies the cost of which is included in S-4 costs.

2. BRIEF DESCRIPTION OF INITIAL SUITE OF EXPERIMENTS

2.1 SURFACE BACKGROUND CHARACTERIZATION

Surface background characterization involves observation of the influences of local geology on the background recorded by the meter cubed detector.

The following are the expected sequence of steps.
Step 1: Borrow the 1 meter cubed detector and learn to operate it.
Step 2: Collect existing data from at various locations.
Step 3: Collect supplementary data at locations with dramatically different local geology around Homestake, Black Hills area, SD
Step 4: Identify trends in the surface background

2.2 UNDERGROUND BACKGROUND CHARACTERIZATION

Underground background characterization involves observation of the interference from cosmic rays and its variation with depth, and also with local geology around Homestake, SD.

Step 1: Collect data with 1 meter cubed detector, preferably at 5 levels of depths or more in Homestake mine to determine cosmic ray related contributions quantitatively for the assay of HPE in the Earth.
Step 2: Collect data with the meter cubed detector, preferably at 3 depths or more, to determine contributions quantitatively to study the influence of local geology for the assay of HPE in the Earth.
Step 3: Identify the interferences from cosmic rays in the measured radiometric data from geoneutrinos.
Step 4: Identify the influences of the local geological parameters on the measured radiometric data from geoneutrinos.
Step 5: Analyze all data from experiments 1 and 2 to separate the geoneutrino data from the deep interior of the Earth from cosmic ray influences and local geology.

2.3 PROOF OF CONCEPT OF GEONEUTRINO RADIOMETRIC ANALYSIS FOR GEOSCIENCES

Proof of concept (POC) involves detection of a local uranium mine with a given precision.

Step 1: Collect surface data with the meter cubed detector at a known mine with proven reserves of uranium.

Step 2: Analyze the data to determine the uranium in the mine based on the first two experiments.

Step 3: Compare the measured uranium value in the mine with the estimated reserve.

Step 4: Draw conclusions about the theory and experiment for the radiometric methodology using geoneutrinos from deep interior of the Earth.

2.4 EXPERIMENTAL STUDY FOR GEOTHERMAL EXPLORATION GEOPHYSICAL STUDIES

Step 1: Collect surface data with the meter cubed detector at known geothermal fields with a wide range of heat flow data.

Step 2: Analyze the data to determine the correlation between the known heat flow data and the measured geoneutrino data based on the first two experiments.

Step 3: Evaluate the geoneutrino method for geothermal exploration.

3. DEVELOPMENT NEEDS PRIOR TO CONDUCTING EXPERIMENTS AT HOMESTAKE

3.1 INFRASTRUCTURE ENGINEERING AND DESIGN

- Surface room 15’ x 15’ x 15’, A/C
- Power Supply 110V @15 Amps of 8 outlets on 4 sides, total of 32 outlets.
- Security
- Clean room class 2000
- Similar room with the above facilities, underground at 4850’
- Crane 2 ton block hoist

3.2 LABORATORY EXPERIMENTS AND THEORETICAL ANALYSIS

- Testing the purity of the materials.
- Determining the K, U, Th in the rock samples from Homestake and local areas
- Custom designed electronics and software
- Monte Carlo simulation capability with MCNP
    - for solid angle determinations (not included in S-4 costs)
    - for shielding design (not included in S-4 costs

4. COST ESTIMATES

4.1 S-4 PROPOSAL COST

Description	**$**
Cerenkov Radiator	50,000
Light Sensors 700@ $1000/piece	700,000
Electronics for the Light Sensors 1000 @ $150/piece	150,000
DAQ Display Acquisition Software	200,000
Shielding	75,000
Sub Total	1,175,000
Contingency	300,000
Total	1,475,000

4.2 ISE PROJECT COST

Description	**$/year**
Full Time Project Manager/Scientist	100,000
2 Assistants	100,000
Secretarial and other administrative help	50,000
Supplies and other project help	50,000
Total	300,000
Total for 5 years	1,500,000

5. TASKS REQUIRED TO REFINE COST ESTIMATE

1. Negotiate borrowing the detector developed (Bowden and Bernstein)
This is under negotiation at this time.
2. If the above task is not feasible come up with task required to design and build from scratch.
This is also in progress

6. SCHEDULES

6.1 S-4 ACTIVITIES ESIMATED TIME AND REQUIRED SEQUENCE OF TASKS

Year 1 - 1st half - Objective: Project start up

- Low radioactivity site selection
- Shielding design
- System components acquisition
- Site preparation
- Personnel recruitment

Year 1 - 2nd half - Objective: Assemble Test Equipment

- Training of personnel and team members
- Assembly of primary test systems
- Calibration of primary systems
- Preliminary test runs above and below ground

- Quality control tests, Quality Assurance tests
- Evidence evaluation for proof of sensitivity

Year 2 - 1st half - Objective: Determination of sensitivity

- Negotiations for Field deployment 1
- Field deployment at a uranium mine site
- Evaluation of data, Quality control tests
- Science analysis and observations 1

Year 2 - 2nd half - Objective: Validation at known locations

- Negotiations for Field deployment 2
- Field deployments at selected Heatflow sites
- Evaluation of data, Quality control tests
- Science analysis and observations 2

Year 3 - 1st half - Objective: Quality assurance tests

- Negotiations for Field deployment 3
- Field deployments at a deep oceanic site
- Evaluation of data, Quality control tests
- Science analysis and observations 3

Year 3 - 2nd half - Objective: Deep Earth Assay design

Synergy with Physics working Groups
Evaluation of science and sensitivity of the investigation from Observations 1, 2, 3
Science analysis and plans for year 4 Funding proposals for years 4 and 5

Years 4 and 5: Discussions in progress
Design of antineutrino detectors with the required detection sensitivity
to assay core of the Earth for heat producing elements.

7. FACILITIES

7.1 SPACE, ACCESS, POWER, ECQUIPMENT, COMMUNICATIONS, SERVICES, SPECIAL MATERIALS

Duration: 3 to 5 years
Depth: 300’ to 4850’
Space: 15’ x 15’ x 15’ below and above ground lab space required
Access: Daily
Power: UPS 120V; AC: 20+/-5 ^{o}C; Humidity: 50%+/-20% Uncontrolled
Equipment: Crane 2 ton block hoist
Communications: Internet
Services:
Radon-free air supply (not through shafts)
Liquid nitrogen supply

Clean room systems
Protocols for entry into the Radiometric Analysis labs
Special materials: Licence for radioactive material storage,
Clean room class 2000: Low Radon Background (mBq/m3) 0.001

8. POINT OF CONTACT FOR FACILITIES

P. ILA PhD Email: pila@MIT.EDU, Phone: 617-253-3387
NW13-263, Dept. of Earth, Atmospheric and Planetary Sciences,
Massachusetts Institute of Technology, Cambridge, MA 02139,

9. EDUCATION AND OUTREACH

Geoneutrino radiometric analysis for geosciences projects has strong potential for Education and Outreach programs because of the multi-disciplines namely geology, geophysics, geochemistry and physics and mainly about Earth's interior and the DUSEL underground experiments.
Education:

1) Offering undergraduate courses:
Ila offers a course in special topics in Earth, Atmospheric and Planetary Sciences, every year during January at MIT. These are usually 5 sessions each of 2 hours. At the end of the course offering, if the course gets selected by MIT's Open Course Ware (OCW) the course will be published on the OCW website. This is a tremendous opportunity both for DUSEL and the project to be visible globally. These courses are free on line. These courses may be offered in any other location, and also may be developed into distance learning.

2) K12 Education: A science teacher from North Dakota is collaborating with Ila.
4 presentations in four North Dakota schools and 1 trip to SUSEL under consideration.

3) Outreach: Rural Sociology department of South Dakota State University is very much interested in collaborating with Ila to develop a community based outreach program especially for the Cheyenne River, Pine Ridge, Red Shirt reservations.

Estimated cost for Education to undergraduate, high school and Outreach to 6 to 9 communities $125,000

10. RISK IDENTIFICATION AND MANAGEMENT

10.1 POTENTIAL PROBLEMS THAT COULD EFFECT SUCCESFUL OUTCOME

If the existing meter cubed antineutrino detector cannot be borrowed in time, then we already have a backup plan to build a detector from scratch. This may have impact on the successful outcome of the time lines

10.2 POTENTIAL PROBLEMS THAT COULD EFFECT OTHER EXPERIMENTAL FACILITIES

We do not foresee any potential problems that could affect other experiments or facility because we do not use any hazardous materials like large quantities of cryogens.

11. CONCLUSION

Addressing the skepticism about our analytical approach and methodology:

1. Understandable because the large detectors are conventional with proven track record, and the

small detectors are cutting edge, the technology just evolving.
2. The scientists who worked with, and are currently working with large detectors are also proposing directional sensitivity for different scientific studies, and radial angular distribution measurements. [8, 30, 32]
3. Small detectors can achieve the goals with different methodology than the large detectors.
4. Small detector advantages and capabilities should be viewed as complementary to those of the large detector.
5. One technology need not exclude the other. Both can co-exist to bring up totality. There is scope and space for both technologies.
6. Small antineutrino detector technology is evolving so fast in other countries, this is the right time to do the project and should not miss the DUSEL opportunity.
7. The meter cubed detector technology and results are already published. So the time, effort and funding is put to best use, by adapting the technology to the next application by implementing the directional sensitivity and radial angular distribution measurements by using source strengths.

Until proven beyond doubt that it is impossible, we are putting forward our best efforts for GRAFG technique and methodology for an opportunity not to be missed!!

12. REFERENCES

1. New Theory of the Earth,
   D. L. Anderson,
   Cambridge University Press, 2007.

2. KamLand: KamLAND results and the radiogenic terrestrial heat,
   G. Fiorentini, M. Lissia, F. Mantovani, B. Ricci,
   arxiv.org/abs/hep-ph/0508048 Aug 2005.

3. Sno+: Geoneutrinos in SNO+,
   M. C. Chen,
   In Neutrino Geophysics: Proceedings of Neutrino Sciences 2005, pages 221-228,
   Springer New York 2007, DOI 10.1007/978-0-387-70771-6.

4. Baksan: Neutrino geophysics at Baksan: On searches for antineutrinos and radiogenic-heat sources in the interior of the Earth,
   G. V. Domogatsky, V. I. Kopeikin, L. A. Mikaelyan and V. V. Sinev,
   Physics of Atomic Nuclei, Vol. 69, No. 1, January, 2006, Pages 43-50.
   DOI 10.1134/S1063778806010078.

5. Borexino: Geoneutrinos in Borexino,
   M. G. Giammarchi, L. Miramonti,
   Earth, Moon, and Planets Vol. 99, No. 1-4, December, 2006, pages 207-220,
   DOI 10.1007/s11038-006-9106-6.

6. Hano Hano: Hano Hano Summary,
   J. Learned,
   Deep Ocean Anti-Neutrino Observatory Workshop (DOANOW)
   Hawai'i, 2007,
   www.phys.hawaii.edu/~sdye/doanow_talks/Learned_DOANOW_2007.ppt

7. LENA: Low energy neutrino astronomy and nucleon decay searches with next generation large underground detectors,
   A. Rubbia,
   3rd Ilias Annual Meeting,LNGS, March 2006,
   http://ilias.in2p3.fr/ilias_site/meetings/documents/FP7_030306/FP7_Rubbia.pdf

8. EARTH : Towards Earth AntineutRino TomograpHy (EARTH),
   R. J. de Meijer, F. D. Smit, F. D. Brooks, R. W. Fearick,
   H. J. Wörtche and F. Mantovani,
   Earth, Moon, and Planets Vol. 99, Numbers 1-4 / December, 2006, pages 193-206,
   DOI 10.1007/s11038-006-9104-8.

9. Hyper Scinitillation Detector- HSD, Homestake:
   Large (50-200 kT) Liquid Scintillation Detector For keV-GeV
   Multidisciplinary Science-Hyper Scinitillation Detector- HSD,
   R. S. Raghavan,
   NSF-DUSEL Workshop, Washington DC, November 3, 2007;
   http://neutrino.lbl.gov/~dusel/HomestakeWorkshopApril2008/HSD-Raghavan-1.ppt

10. LBL Proposal: Geoneutrino Experiment at Homestake:
    N. Tolich, Y. -D.Chan, C. A. Currat, B. K. Fujikawa, R. Henning, K. T. Lesko,
    A. W. P. Poon, M. P. Decowski, J. Wang, K. Tolich,
    Earth, Moon, and Planets , 2006 v. 99, pages 229–240,
    DOI 10.1007/s11038-006-9112-8

11. Geo-neutrinos: a new probe of Earth's interior
    G. Fiorentini, M. Lissia, F. Mantovani, R. Vannucci
    Earth and Planetary Science Letters, 2005, v.238, p. 235– 247
    arxiv.org/pdf/physics/0508019

12. Geo-neutrinos: A systematic approach to uncertainties and correlations,
    G.L. Fogli, E. Lisi, A. Palazzo, A.M. Rotunno,
    arXiv:physics/0608025, 2006. Neutrino Science 2005, Honolulu, Hawaii, Dec. 2005.

13. Compositional Model for the Earth's Core
    W. F. McDonough in Treatise on Geochemistry
    in The Mantle and Core, Treatise on Geochemistry, Volume 2, pages 547-568,
    Ed. R. W. Carlson, Elsevier San Diego, 2005.

14. The composition of the Earth,
    W. F. McDonough and S.-S. Sun,

Chem. Geol. 120 (1995) 223–253.

15. Chemical differentiation of the Earth: the relationship between mantle, continental crust, and oceanic crust,
A. W. Hofmann,
Earth Planet. Sci. Lett. 90 (1988) 297–314.

16. Earth's heat flux revised and linked to chemistry,
A. M. Hofmeister, R. E. Criss,
Tectonophysics, 2005, 395, 159-177.

17. Comments on "Earth's heat flux revised and linked to chemistr, A.M. Hofmeister and R. E. Criss", R. Von Herzen, E. E. Davis, A. T. Fisher, C. A. Stein, H. N. Pollack,
Tectonophysics, 409 (2005) 193–198.

18. Reply to comments by R. Von Herzen, E.E. Davis, A.T. Fisher, C.A. Stein and H.N. Pollack on Earth's heat flux revised and linked to chemistry.
A. M. Hofmeister, and R. E. Criss,
Tectonophysics 409 (2005) 199–203.

19. Estimates of heat flow from Cenozoic seafloor using global depth and age data,
M. Wei, and D. Sandwell, 2006,
Tectonophysics 417, 325–335.

20. Comment on "Estimates of heat flow from Cenozoic seafloor using global depth and age data, M. Wei and D. Sandwell",
A.M. Hofmeister and R. E. Criss,
Tectonophysics 428 (2006) 95–100.

21. Experimental evidence that potassium is a substantial radioactive heat source in planetary cores,
V. Rama Murthy, W. V. Westrenen, Y. W. Fei,
Nature 423, 163–165 (2003); doi:10.1038/nature01560.

22. Nuclear Georeactor Generation of Earth's Geomagnetic Field,
J. M. Herndon,
arXiv:0707.2850v4 [physics.geo-ph] Jul 19, 2007.

23. Chapter 11. Geochemistry of the Solid Earth I: Mantle and Core in Geochemistry,
W. M. White,
www.imwa.info/geochemistry/Chapters/Chapter11.pdf

24. Trace Elements in Magmas: A Theoretical Treatment,
D. M. Shaw,
Cambridge University Press 1964

25. Attempt to detect the antineutrinos from a nuclear reactor by the Cl^{37} (antineutrino, negative electron) A^{37} reaction.
R. Davis, Jr. Phy. Rev. 1955, vol. 97, no. 3, 766-769.

26. Experimental investigation of geologically produced antineutrinos with KamLAND,
KamLand Collaboration, T. Araki et al.,
Nature 436 (2005) 499-503.

27. Electron antineutrino search at the Sudbury Neutrino Observatory,
SNO Collaboration,
Phy. Rev. D, vol. 70, 093014 1-8 2004.

28. Search for electron antineutrino interactions with the Borexino Counting Test Facility at Gran Sasso
Borexino Collaboration, M. Balata et al
arXiv:hep-ex/0602027v2 10May, 2006

29. Astrophysical Neutrinos: 20th Century and Beyond
J. N. Bahcall,
Nucl. Phy. B (Proc. Suppl.) 91 (2001) 9-17.

30. Neutrino tomography:
Learning about the Earth's interior using the propagation of neutrinos,
W. Winter
Neutrino sciences 2005: Neutrino geophysics, December 16, 2005

31. Imaging the Earth's Interior: the Angular Distribution of Terrestrial Neutrinos,
B. D. Fields and K. A. Hochmuth,
arXiV:hep-ph/0404001v1, 31 May2004, p. 1-24.

32. On the Possibility of Directional Analysis for Geo-neutrinos,
M. Batygov,
in Neutrino Geophysics: Proceedings of Neutrino Sciences 2005,
Ed. S. T. Dye, Pages 183-192, DOI 10.1007/978-0-387-70771-6
www.phys.hawaii.edu/~jelena/post/hnsc/Batygov_directionality.ppt

33. A short-atlas of beta-ray spectra,
W. G. Cross, H. Ing and N. Freedman,
Phys. Med. Biol. 28 (1983)1251-1260.

34. An Assessment of Antineutrino Detection as a Tool for Monitoring Nuclear Explosions,
A. Bernstein, T. West, V. Gupta,
Science & Global Security, 2001, vol. 9 pp 235-255

35. Monitoring the thermal power of nuclear reactors with a prototype cubic meter antineutrino detector,
A. Bernstein, N. S. Bowden, A. Misner and T. Palmer,

J. Appl. Phy. 103, 2008, 074905, 1-10.

36. The MUNU experiment, general description,
MUNU Collaboration,
Nucl. Instr. and Meth. in Phy. Res. A 396 (1997) 115-129.

37. Neutrino Astrophysics,
J. N. Bahcall,
Cambridge University Press, 1989.