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1. Goal

The aim of the programme Earth AntineutRino TomograpHy (EARTH) is to eventually make a 3D-map of the radiogenic heat sources of our planet. The 3D-tomography has to be achieved by direction-sensitive measurements of antineutrinos, released in radiogenic processes like natural decay and fission. Direction sensitivity is in principle mainly embedded in the neutron produced in the antineutrino capture reaction on a proton.

Direction sensitive antineutrino is also a very much wanted tool for establishing fundamental properties of antineutrinos. Considerable progress has been made in neutrino physics in the past decade and one of the remaining questions (the value of the mixing angle θ_{13}) can be determined by direction sensitive antineutrino detection (*P. Huber et al.,*.2005*)*

2. Collaboration framework.

The idea for EARTH originated at the KVI, Groningen, but was moved to a Foundation (Stichting EARTH) founded by the University of Groningen, ASTRON and Stichting JADE, a private foundation. The Stichting EARTH has a Board and a Council of Advice and is located in Peize, near Groningen.

Board Stichting EARTH:	**Council of Advise EARTH:**
Dr. Jacob Gelt Dekker, Entrepreneur, Chairman; Prof.dr. Reinhard Morgenstern, Secretary; Henk Koopmans, director Sensor Universe, Thesaurie. Prof.dr. Krish Bharuth Ram, ex-Director iThemba Labs.	Prof. dr. Gerard ‘t Hooft, Theoretical Physics, Utrecht University; Prof. Simon Kuipers, Chairman Board Groningen University. Prof. Dr. Wubbo Ockels, Space Technology, Delft University of Technology; Em. Prof.dr. Harry Priem, Geoscience. Utrecht University.

The Stichting EARTH has established an official collaboration by means of a Memorandum of Understanding with the South African national laboratory iThemba LABS, the University of Stellenbosch (US), the University of Cape Town (UCT) and the University of the Western Cape (UWC), all four situated in the vicinity of Cape Town. In addition there is collaboration with the Physics Department of the University of Jyväskylä, Finland, ASTRON and the Faculty of Earth and Life Sciences at the Vrije Universiteit, Amsterdam.

In addition to a Board and a Council of Advice, the Stichting has established an Industrial Consortium of a number of companies in the (Northern) Netherlands. EARTH participates in Sensor Universe, a sensor development initiative by the three northern provinces in the Netherlands.

3. Developments and present status.

The initial stage of the programme has focussed on two aspects: phase one, on detector development and testing as well as the assessment of radiogenic sources based on the current scientific knowledge.

3.a. Detector development.
The first phase of detector development has been carried out mainly in South Africa by using the expertise present at UCT (prof. Frank Brooks) and iThemba LABS (dr. F.D. Smit) on neutron detection. An existing small detector cell filled with liquid scintillation and loaded with 5% ^{10}B was used to mimic delayed coincidences and pulse-shape properties. These test were accompanied by Monte Carlo simulations of the neutron capture process both for captured antineutrinos from natural decay as well as fission. The simulations stress the need for early capture of the neutron to preserve the direction information carried by the incoming antineutrino. The results have been published (de Meijer *et al*, 2006) and (Smit *et al,* 2006).

Subsequently, Monte Carlo simulations have been expanded to also include the positron properties. These simulations are presently being carried out at the Universities of Cape Town and Stellenbosch as part of MSc projects.

In parallel to the detector tests at the Cape, EARTH purchased boron-doped plastic detectors and made them available to researchers at the University of Groningen and one of the industrial partners. They developed an algorithm that allows pulse-shape analysis of fast digitised pulses. In their work it was demonstrated that under optimal conditions a time difference of 10ps could be obtained for pulse-generator pulses with a rise time of 4 ns. Time difference measurements of this order of magnitude, in principle, open a new way towards direction-sensitive measurements of antineutrinos. By measuring the positions of the positron and the neutron, the difference vector can be used as an estimate of the incoming antineutrino direction.

Based on this achievement a design was worked out for GiZA (Geoneutrinos in ZA), a next step detector. The main aim for this detector is a precise characterisation of an antineutrino event by measuring pulse properties of both the positron and neutron, as well as their timing properties. A tetrahedron-shaped detector has been proposed with a PMT at each corner. The optical properties of this detector have been optimised in Monte Carlo simulations by ASTRON. This work has been completed and the mechanical construction is under design.

In a parallel development the scintillation liquid will be optimised. For that purpose a number of small test cells have been designed and will be constructed.

3.b. Assessment of radiogenic heat sources in the Earth's interior.
Recent developments in geochemical models and increases in precision of isotopic dating techniques have led to new insights in the early history (< 100 Ma) of our planet and its moon. The present knowledge leads to a concentration of U, Th and Pu in the Core-Mantle Boundary (CMB) or D" region. About a year ago it was realised that under the temperatures and pressures in the CMB a mineral, calcium perovskite, is formed which absorbs U, Th and Pu several orders of magnitude readily than the other dominant minerals in the CMB. If the CMB was homogeneous these actinides would be nicely dispersed over the CMB and decay in a natural way (including spontaneous fission). Heterogeneities, e.g. due to density effects, leading to an order of magnitude higher conentration of these actinides would create a situation in which a natural georeactor could ignite and afterwards stay operational, even possibly up to present.

In a paper (*de Meijer and van Westrenen*, 2008, see also *Ball*, 2008) the consequences of such a georeactor. In addition to possible identification and location of such georeactors by antineutrino tomography, the georeactors could lead to changes in isotopic composition of a number of elements, most clearly in He and Xe, relative to their abundances in the Earth's atmosphere. The calculated isotopic ratios are consistent with the deviating isotopic compositions in gasses from deep wells.

4. Near future plans.

4.a Detector development.
It is expected that by the beginning of October the smaller test cells will become available for testing in the laboratory. In addition an effort? is being made to develop new scintillating materials with good properties for positrons and neutrons. Preferably we aim for less expensive materials such as scintillating plastics. Special attention is paid to sufficient pulse-shape identification of positrons and neutrons.

After laboratory testing of the smaller cells, a choice will be made to fill the GiZA detector. Once these laboratory tests have been completed the plan is to install the detector outside the containment wall of one of the reactors at the Koeberg nuclear power plant, about 30km north of Cape Town. At this stage direction sensitivity is not the main issue, the tests concentrate on antineutrino identification, testing position determination by means of triangulation and background reduction. These tests should lead to a proto-type detector design. With this proto-type the direction sensitivity will be tested, and if successful, this detector will be the step towards a detector system for monitoring and safeguarding nuclear power plants.

4.b. Assessment of radiogenic heat sources in the Earth's interior.
The work on the radiogenic heat sources will continue. For georeactors in the CMB, a model is being developed linking a supercritical georeactor to the formation of the Moon. Work has started on assessing the role that georeactors may have played also in other planets of our solar system. For Earth the role centres on the issues of mantle plumes, large scale mineralisations (e.g. of gold and platinum in Africa) and abiotic natural gas in the deeper parts of the Earth (eg. possibly the recent gas fields off the Brazilian coast)

4.c. Financing.
As in the past, we concentrate on Public-Private Partnerships in financing the development of our programme. With clear applications in sight, we have received encouraging support for the near future financing of our plans.

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