



Progress Report July 2005–January 2006

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This document presents an overview of the essential events related to the Earth Antineutrino Tomography (EARTH) programme in the period July-December, 2005. This is the fifth progress report: the previous ones covered the period May-August 2004 and September-October 2004, November 2004-January 2005 and February-June 2005.

General situation.

Organisation

In this reporting period some important developments took place. As mentioned in the previous progress report the Advisory Board of EARTH met to discuss the future structure of EARTH on 11 April 2005. It was generally agreed that EARTH is an ambitious programme with a wide scientific and technological scope. Only part of the scope, the development of a directional sensitive antineutrino detector, fits in the mission of the KVI. It was therefore suggested and accepted that a foundation should be created with the goal "To support and maintain scientific and technological development, which may lead to a mapping of the radiogenic heat sources in the Earth's interior by detection of antineutrinos". The founders will be the University of Groningen, ASTRON and the Foundation JADE. The foundation takes over all general activities of EARTH from the KVI. The role of the KVI will be that of one of the partners in detector development. On 1 September the Stichting (Foundation) Earth Antineutrino Tomography (EARTH) was officially established and its board consists of Mr. Jacob Gelt Dekker (Foundation JADE) as chairman, Prof.dr. Reinhard Morgenstern as secretary/ treasurer and Prof.dr. Harvey Butcher (ASTRON) vice-chairman. At its first board meeting the EARTH-board nominated prof.dr. Rob de Meijer director of the Foundation EARTH.

Rob de Meijer reached the age of 65 in July 2005. This means that he had to retire on 1 August 2005. On 6 September 2005 there was a farewell symposium in the auditorium of the University of Groningen under the title "The Earth Inside Out", followed by a farewell lecture titled "Terra Incognita". The symposium comprised four lectures on EARTH related topics, by dr. Uli Harms (GFZ-Potsdam), prof.dr. Cristoph Clauser (University of Aachen), prof.dr Giovanni Fiorentini (University of Ferrara) and mr. Jacob Dekker. The symposium was attended by about one hundred people. The farewell lecture presented the ideas behind the EARTH programme and was attended by about 300 people.

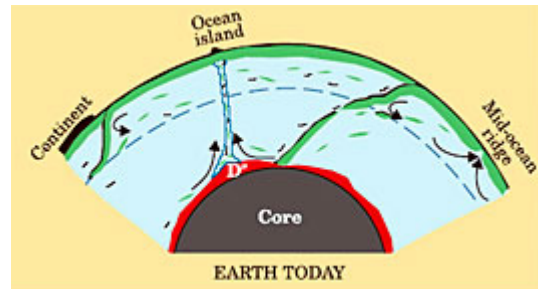
International development

On 1 July, 2005 the journal Science published a list of 25 topics which they consider as a priority list for scientific development in the coming 25 years. Rather high on their priority list is the question "How Does Earth's Interior Work" (Science, vol 309, p87). This is exactly the question driving our EARTH programme and hence the programme should provide an answer.

A few weeks later on 27 July, 2005 the journal Nature published the experimental confirmation of antineutrinos from the Earth's interior (geoneutrinos), measured at the large facility KamLAND at Kamioka, Japan (Nature, vol 436, p499-503). This facility is one of the guidelines for EARTH and our set-up aims to be a next generation of such detectors.



In September 2005 *Physics Today* (p 19-21) published an article in which evidence is presented on a new hypothesis on the Earth interior. It suggests that part of the subducted crust and lower mantle ends up at the mantle core boundary and becomes the source for mantle plumes (see adjacent figure taken from *Physics Today*). The boundary layer is hypothesised to contain about 40% of the planet's natural radiogenic nuclides K, Th and U and could be a major source of geoneutrinos.



A new view on the Earth's Interior according to Boyet and Carlson. The dashed line represents the 660km depth line.

In October 2005 the *Scientific American* issued a Special Edition "Our Ever Changing EARTH" (vol 15/2) describing the present state of the knowledge and also pointing to one of the most dynamic parts: the core-mantle boundary layer. To resolve the heterogeneity of the structures in that layer a high resolution methods are very welcome. With its direction sensitivity the foreseen EARTH telescope systems will be able to see details on a 150km scale and fulfil this wish.

Funding applications

With the start-up funding by ASTRON and the matching in manpower by the KVI, the programme was declared started as of 1 September 2004. Several attempts to obtain a written confirmation from the South African National Research Foundation (NRF) have not yet been obtained, but in practice the people at iThemba LABS and the University of Cape Town (UCT) are working on the programme as agreed. As of May 2005 iThemba LABS has a new director, prof. Krish Bharuth-Ram and deputy director prof. Zeblon Vilakazy. Discussions with the directors on funding are planned when prof. de Meijer is in South Africa.

A proposal was submitted to the Dutch Organisation for Physics Research FOM on 21 March. The funding is requested for developing, building and testing of a directional sensitive antineutrino detector. The application was not granted. Our application to the EU programme NEST/Adventure submitted on 11 March met a similar fate. Despite the unfortunate decisions the collaboration with some European partners was strengthened.

Innovatiesubsidie Samenwerkingsprojecten (IS).

To obtain funding for the ongoing and upcoming projects in the first phase a variety of funding possibilities has been continued to be explored. Since May 2004 we have worked with Technology Centre Northern-Netherlands (TCNN) on the preparation of two applications in the programme *Innovatiesubsidie Samenwerkingsprojecten (IS)* of the Dutch Ministry of Economic Affairs. One is focussing on the detector and electronics development, the other is aiming at investigating the feasibility of drilling for an EARTH antenna on Curaçao. In addition, financial support for the antenna part is being sought from funds specially dedicated to collaborations with the Netherlands Antilles and in particular Curaçao.

On 12 May the international proposal for EARTH-DRILL (the antenna part) was submitted to SenterNovem as an application for IS-funding. In this proposal the three Geoscience partners of the NEST proposal, Focus Oil and Gas, TCNN, EARTH Foundation/ASTRON are partners with and Aqualectra (Curaçao) and Geophysica (Aachen, Germany). The application has not been honoured.

In the second half of June we started the preparation for the submission of the EARTH-SENSOR proposal. After discussions with SenterNovem the emphasis of the project



changed to the industrial topic of developing a solid-state image intensifier. For this project a number of novel developments have to be made, which are fully aligned with the detector development of EARTH-SENSOR. The application was rewritten and renamed, and submitted under the name of Low-Intensity Photon Counting (LIPCO) to SenterNovem for IS-funding on 9 September 2005. The application was not honoured.

Parallel to this application our industrial partner and coordinator for LIPCO, Hi-Light Opto Electronics has applied for and obtained a work permit for dr. Matjaz Vencelj from Ljubljana, Slovenia. Dr. Vencelj works part time at the KVI on the photonics part of the detector development in collaboration with dr. Heinrich Wörtche.

NWO.

The Dutch Organisation of Scientific Research (NWO) has been asked by the Dutch ministers of Education, Culture and Sciences (OC&W) and of Economic Affairs (EZ) to advise them on funding of large-scale research facilities. The call for proposals opened officially on 26 September 2005 and closed on 14 October 2005. The Stichting EARTH submitted a proposal “Telescope for Low-Energy Neutrino based Sciences (TeleLENS)”, covering the development of the direction-sensitive antineutrino detector including in the first phase the Proof of Principle at a nuclear power plant and the proof of concept of an underground facility at Curaçao and if successful the construction and installation of the TeleLENS facility.

By the end of October we were notified that the proposal was received and met the criteria set for further evaluation. A final decision will be announced by the minister of OC&W around 7 December 2005. There were 42 proposals submitted in total exceeding the available budget (100M€) by a factor of fifteen. This on the one hand underlines the creativity of Dutch scientists and on the other hand is an indication of the chances for funding. TeleLENS was not among the five proposals that were funded.

SenterNovem awarded the application of five industrial partners for Kennisvouchers (Knowledge vouchers). These vouchers allow the companies to jointly ask a knowledge institution for access to their experience. The companies decided to ask the KVI/RuG to design and construct a box for testing the EARTH detectors under various conditions of temperature and humidity. Inside the box test detectors, electronics and radioactive sources can be placed. The box is equipped with various feed-troughs for cables and leads. In the meantime the design has been approved and the box is under construction.

Applications in preparation

In addition to the more large-scale funding applications we continue to look for small-scale projects that focus on applications in industry and Earth Sciences. One of the fields where the physics of Earth meets the Earth Sciences is in the tomography. In the last decades geophysicists have greatly improved models and techniques related to seismic tomography. A meeting was held with dr. Arie van den Berg, Department of Earth Sciences at the Utrecht University, to investigate a joint proposal to link the tomographic detection of antineutrinos from localised radiogenic heat sources to convection currents in the mantle. A proposal for funding by the FOM, the physics branch of NWO and ALW, the earth sciences branch of NWO is presently being prepared.

The results of a test drilling on Westpunt, Curaçao revealed that water at 70m depth is about 5 to 10°C cooler than at the surface and that the temperature profile over that distance closely follows that of the surrounding ocean waters. To further investigate the feasibility of extracting “cold energy” from the shallow or even deeper underground at the initial and



surrounding locations near Westpunt has led to preparations for a PESP and PSNA applications by Desert Greenhouse, Kura Hulanda Lodges, Focus Oil and Gas and Stichting EARTH. The PESP and PSNA programmes are funding possibilities of the Dutch Ministry of Economic Affairs (EZ). The cold energy can directly be applied for cooling greenhouses and for air-conditioning of lodges, without the otherwise required power consumption.

Samples of the drill cuttings, taken at the surface (limestone) and at 20m depth (diarite) have been analysed on radionuclide concentrations. As expected the concentrations are rather low, especially in the 20m sample. The samples are presently being analysed on thermal properties at Aachen.

Curaçao

Education

An antenna on Curaçao will require well trained and educated people to operate it. As such training takes time we have to interest high school students in science studies. During our visit to Curaçao we met with representatives of the UNA and some of the high schools at Curaçao and with the Stichting Studiefinanciering Curaçao. With the latter we discussed possibilities of stimulating high-school students to take up studying in a science direction. With the UNA we discussed their role in educating the science students and possibilities for collaboration with the University of Groningen. In addition the UNA has offered to take on a coordinating role in a Hisparc project on Curaçao for high schools. Hisparc is a Dutch project (see www.hisparc.nl) in which pupils build a detector for high-energy cosmic rays and measure very-high energy cosmic events in coincidence measurements between signals occurring in detectors placed at some distance apart. We have established a contact between the Dean of the Technical Faculty of the UNA and the Dutch coordinator.

During her visit Dr. Narain again expressed the interest in the EARTH programme. Within the possibilities the UNA likes to participate after the project gets off the ground. The main contribution will be in the education and training programme. One possibility may be for students, after the Bachelors degree, to take a master education at the RuG specialising in instrumentation. To make an actual start requires the purchase of HiSparc detector unit. Thus far the UNA has not been able to free this amount in their budget.

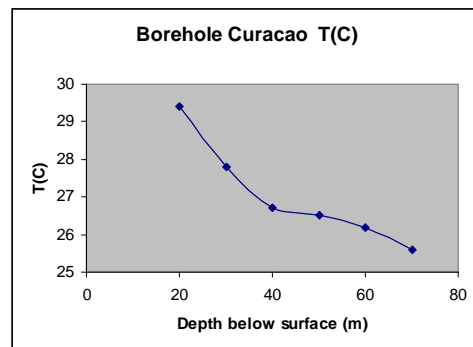
Exploratory drilling.

For the telescope construction on Curaçao, we are in contact with the International Scientific Continental Drilling Programme (ICDP), coordinated from the GeoForschungsZentrum, Potsdam (GFZ). The Scientific Advisory Board of ICDP has given GFZ the task to assist us in the planning and execution of drilling activities on Curaçao. The original idea for Curaçao was to drill individual vertical shafts, the experience of GFZ/ICDP at their location at Windischesschenbach, Bavaria, Germany, has helped us in modifying our plans into the present plans for the TeleLENS facility. One of the concerns for the facility was the temperature profile as function of depth. It was quickly realised that two options were realistic: increasing or decreasing in depth. Both options could be of interest to the energy supply on the Island of Curaçao.

To further explore the options we initiated contacts with Aquallectra, the energy and water supplier of the Island, Kura Hulanda Lodges and the European experts on geothermal mining: The Institute of Applied Geophysics of the University of Aachen and its spin-off company Geophysica BmbH. It was the initiative of Kura Hulanda Lodges and Desert Greenhouse to make a first test drill to 70m which informed us we are dealing with decreasing

temperatures (see figure), following more or less the temperature profile of the ocean waters. The preliminary results also indicate that the underground contains highly permeable layers. To explore the feasibility of cold-energy extraction, a second drill was started to reach 130m in the middle of January 2006. The main goal is to establish the temperature to greater depth. The outcome of this second drill will be input to a request for funding to the Ministry of Economic Affairs.

This development indicates that a broad-scale programme with a clear scientific goal leads to unexpected spin-offs. In our case these spin-offs started even before the programme got fully underway!



Temperature versus depth in the borehole at Curaçao

Detector development

In the last three progress reports the first measurements on a test cell at iThemba LABS, South Africa were described. These measurements simulated the basic principle for antineutrino detection, namely the delayed coincidence method, with the use of a neutron source and a ^{10}B -loaded scintillator. Moreover the data showed that signals produced by γ -radiation and neutrons can be distinguished by analysing the pulse shapes of the digitised pulses. Moreover simulation calculations were made to investigate the dependence of the directionality on the diameter of the detector cells. The simulations stress the importance of ^{10}B (boron-10) being present in the detector material. This addition leads to a capture of the neutron by boron, followed by the emission of an α -particle. The properties of boron lead to an early capture of the neutron, such that it has not lost too much of its original direction information. The α -particle is stopped instantly and its signal therefore indicates the stopping location of the neutron. Another result of the simulations is that one can estimate the degree of direction sensitivity as function of the diameter of the detector.

The feasibility of using a ^{10}B -loaded liquid organic scintillator to detect double pulse events from inverse beta decay of the neutron using double pulse events generated by neutrons from a ^{252}Cf source. The first pulse is due to the recoil proton produced when the neutron initially scatters off a hydrogen nucleus in the scintillator. The second pulse is produced by the alpha particle and ^7Li recoil that are emitted after the neutron is moderated and eventually captured by a ^{10}B nucleus. In the antineutrino detector that is ultimately envisaged the first pulse will be produced by the positron emitted following antineutrino capture by a proton. Scintillation pulse shape discrimination will then be used to *reject* background due to neutron double-pulse events like those being studied in the test measurements.

In the previous progress report it was shown that the distribution of the number of events as a function of the time T between first and second pulses drops off exponentially with a decay time $T_0 = 0.4 \mu\text{s}$. The value of T_0 is expected that depends on the concentration of ^{10}B in the liquid scintillator, the detector geometry and perhaps other factors too.

At the KVI a test box has been designed to test detectors under various controlled conditions. The box is presently under construction and should be ready in the beginning of February 2006. This project is financed by the “Kennisvouchers” (see IS-funding) provided by SenterNovem to the EARTH industrial partners. Moreover we ordered two boron-loaded plastic detectors, with photomultipliers mounted on both sides from our partner Scionix. The

detectors were delivered at the end of November 2005. With these two pieces of equipment and the arrival of dr. Vencelj the detector development will start.

Scientific contacts

The symposium “The Earth Inside Out” was a good opportunity to firm contacts with a number of scientists. With speakers from RWTH-University in Aachen, the German Geological Research Centre, GFZ, in Potsdam, and The Physics Department of the University of Ferrara, Italy, both the physics and earth science aspects were brought together. The symposium also led to a meeting in Aachen with RWTH on the possibilities of mining geothermal energy on Curaçao.

In August and September dr. Mantovani (University of Siena at St Giovanni di Valdano, Italy) spent a few weeks at the KVI. It was an opportunity to discuss some aspects of the need for directionality. His calculations with a uniform radionuclide distribution in the mantle and no neutrinos produced in the core indicate that a large part of the geoneutrinos to be detected at Curaçao are coming from the crust and that already a directional sensitivity of about 30° provides some insight in the actual distribution between radionuclides. A telescope as planned for Curaçao will already provide a wealth of new information on the radionuclide distribution in the crust and the mantle and will already indicate the degree of heterogeneity in the radionuclide distributions. For Curaçao the maximum contribution from the crust is expected to come from mountain ranges in the southwest (Venezuela) and a minimum from the region to the north-east

In December 2005 an international geoneutrino conference was held at Honolulu, Hawaii. This first Neutrino Geophysics Conference was organised by the Physics Department of the University of Hawaii. The conference was exceptional in the sense that it brought together for the first time scientists from various disciplines who explained to each other what is known and unknown about the Interior of the Earth and what tools and measurements are needed to improve our knowledge on the subject. It is hoped that the improved knowledge will lead to a better understanding of phenomena at the Earth surface, with a, sometimes, large economic and social impact. Earthquakes and tsunamis are obvious examples, but also the alterations in the geomagnetic field. This field acts as a protective shield against too high doses of radiation and prevents the blow up and gradual erosion of our atmosphere. More information on the conference and the slides of the presentations can be found on http://www.phys.hawaii.edu/~jelena/hnsc_talks.html.

About 50 scientists attended this conference. EARTH was represented by Ricky Smit (iThemba Labs) and Rob de Meijer. Rob’s presentation of the EARTH programme started with a broad view of the aim of EARTH with ten telescopes for 3D tomography. Subsequently he focussed on the initial detector development mainly carried out in South Africa. He points out that the EARTH team focuses on the proof of principle test for direction sensitive measurements. He shows the results of the simulations that indicate that the direction sensitivity is feasible with small diameter detectors. He also shows the advantage of loading the liquid scintillators with ^{10}B . This leads to a better preservation of the direction information. In laboratory experiments in which the antineutrino capture is mimicked by neutron scattering, a two orders of magnitude reduction, compared to KamLAND detector, in the coincidence time window between positron and neutron detection is found. Moreover the data indicate that further selection by pulse-shape discrimination is feasible. The talk is well received and the audience agrees that after a successful “proof of principle” test considerable technological challenges have to be overcome.

In summary, this conference was a very successful meeting of various disciplines and a rare exchange of knowledge and ideas. The conference was held in an open atmosphere and



stimulated broad discussions. The presentations and discussions have convinced us more than ever to continue the work on EARTH. They are an extra stimulus to show, in a proof of principle experiment, that direction-sensitive detection of low-energy antineutrinos is possible. The international community is eagerly looking forward to the outcome of this proof.

Website

Our website has moved to www.geoneutrino.nl.

Seminars and presentations.

Groningen, 6 September 2005, Symposium *The Earth Inside Out*:

Chairman: Prof.dr. H.R. Butcher, ASTRON.

Dr. U. Harms, GFZ-Potsdam/ICDP, Germany, *Deep Scientific Drilling*.

Prof.dr. C. Clauser, RWTH Aachen, Germany, *Heat production in the Earth*,

Prof.dr. G. Fiorentini, University of Ferrara, Italy,

Drs. J.G. Dekker, Entrepreneur Curaçao,

Groningen, 6 September,

Prof.dr. R.J. de Meijer, *Terra Incognita*.

Groningen, 8 September

Dr. F. Mantovani, University of Sienna at St. Giovanni di Valdano, Neutrino and Energetics of the Earth

Honolulu, 15 December 2005,

Prof.dr. R.J. de Meijer, *Towards Earth Antineutrino Tomography*.

Publications and publicity.

- Scientific journals.

R.J. de Meijer, H.J. Wörtche, E.R. van der Graaf, R.W Fearick, F.D. Smit and R.G.E. Timmermans, *Geoneutrinos onthullen het binnenste van de Aarde*, Ned. Tijdschrift voor Natuurkunde, **71/10**, 332-336, 2005.

- Popular scientific journals and newspapers
- Radio and TV interviews with Rob de Meijer:

14 July, Radio Noord;

28 July, Radio: VPRO-Noorderlicht, Boodschappers uit het binnenste van de Aarde;

5 September, TV-Noord

7 September, Radio1 Journaal;

September, Radio: Teleac

19 September, Radio: Met het Oog op Morgen

- Theatre

21 September, Groningen, Theater Adhoc, Adhoc#1

- Reports

EARTH REP-008: *Verslag van een bespreking boring op Curaçao*.

EARTH REP-009: *Report on the NeutrinoGeophysics Conference, Honolulu, Hawaii, December 14-16, 2005*

