Video on Natural Analogues

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International Video Project on

Natural Analogues

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What's the history?

A natural analogue can be defined as a natural process which has occurred in the past and is studied in order to test predictions about the future evolution of similar processes. In recent years, natural analogues have been used increasingly to test the mathematical models required for repository performance assessment. Analogues are, however, also of considerable use in public relations as they allow many of the principles involved in demonstrating repository safety to be illustrated in a clear manner using natural systems with which man is familiar. The international Natural Analogue Working Group (NAWG), organised under the auspices of the CEC, has recognised that such PR applications are of considerable importance and should be supported from a technical level. At the NAWG meeting in Pitlochry, Scotland (June 1990), it was recommended that the possibilities for making a video film on this topic be investigated and Nagra was requested to take the lead role in setting up such a project.

Why and for Whom?

The main aim of the video is to use photogenic analogue studies to show that the public concern about the very long timescales of nuclear waste disposal is recognised and that studies are underway to test predictions of the future by examining the past. It is not intended to present a pronuclear stance. The aspect of long-term prediction clearly presents many problems for a lay audience, however, and it is hoped that the video will contribute to the general education which is clearly a pre-requisite for public acceptance. The target audience is the technically interested layman. It is intended that the video should be suitable for TV broadcast or for showing in schools; therefore it should not exceed 30 minutes.

Who is doing what?

Practically, Nagra manages this project, which is coordinated by the author. The reviews of various options were carried out by a technical committee and members of a core group of the steering committee formed by delegates of the participating agencies. The technical committee consists of natural analogue experts (Dr. J.A.T. Smellie, Conterra/Sweden; Dr. N.A. Chapman, Intera/UK; Dr. W.R. Alexander, University of Berne/Switzerland and Dr. I.G. McKinley, Nagra/Switzerland). All members are, or have been, members of the NAWG and have been directly involved in one or more of the selected analogues. The committee is also widely experienced in nuclear waste disposal and is especially well acquainted with CEC research and the national programmes of Canada, Sweden, Finland, France, Japan, Spain, Switzerland, the UK and the USA. The members of the core group are K. Schaller, CEC/Brussels; J. Lindqvist, SKB/Sweden and Dr. M. Güntensperger, Nagra/Switzerland. The steering committee (delegates of all participating agencies) will be responsible for all general decisions.

What has been done?

As we focused our ideas on an English language master, we initially tried to interest UK film makers; in parallel, we discussed the project with other potential producers in Switzerland/Germany and in France. Only two approaches led to detailed proposals for the project. The proposals were presented at a meeting in Brussels (2. April 1992) to the members of the video project core group. With the information provided during this meeting the two potential producer teams were then commissioned to write a draft script. Based on these scripts the members of the core group selected the production team: Dr. M. Weiser (Switzerland) and C. Reppmann (Germany).

The steering committee of the video project decided that there will be a preproduction phase, then a „Stop or Go meeting" and finally, if so decided, full production. It was further decided that all participating agencies pay equal shares and that each of the two production phases of the video will involve two agreements, one between the participating agencies and Nagra and the other between the producers and Nagra. The chosen team was engaged to start the preproduction, in extenso to make the necessary reconnaissance tours and write a detailed script and storyboard.

Who is participating?

The following agencies have signed the letter of agreement covering preproduction of the Natural Analogues Video:

AECL (Canada)

CEC (Brussels, Belgium)

ENRESA (Spain)

NIREX (United Kingdom)

SKB (Sweden)

USDOE (USA)

NAGRA (Switzerland).

PNC (Japan), ANDRA (France), ONDRAF (Belgium) are further interested agencies but they have not yet joined the project.

Where exactly are we now?

In December 1992, the technical committee and the core group met in Zurich to discuss the draft of the detailed script and storyboard. After a very packed working day and subsequent reworking of the text of the script, a revised script and storyboard was approved by the technical committee and the core group and sent to the delegates of the participating (steering committee) and potentially participating agencies, together with an invitation to meet in Zurich in January 1993. This meeting is held to decide whether or not to proceed with full production of the video. The actual outcome of this meeting will be reported by the author during the presentation in Karlovy Vary on February 3rd 1993.

What does it cost?

Exact costs will depend on the script and storyboard chosen but, with reconnaissance tours and filming at analogue sites in 4 countries (Brazil, Canada, UK and Italy), the video production cost will be approximately US$ 500,000.–. This figure should cover the preproduction, production and postproduction, the English master and original German, French, Spanish and Swedish versions.

What is the schedule?

The decision whether to stop the project or to proceed with video production should be taken in early spring. Actual production can then start in April/May. Postproduction will take place during July and August. The English master should be available to the participating agencies in late September 1993.

What is the video about?

The following extracts from the script give a flavour of the approach taken and of the technical/scientific studies illustrated in the video.

Predicting the future is an old, old wish of mankind, a wish as old as the hills! Our ancestors used occultism, mystical devices, dance and fire-magic. Later the arsenal of soothsaying was extended to include plant and animal substances: mandrake, opium and curare. The microscope, the pendulum, the telescope ... and the computer followed. Science and technology have developed rapidly and the accuracy of predictions has greatly improved. In 1975, the earthquake which devastated the city of Hai-Cheng was predicted. The three million inhabitants were forewarned and thus avoided death.

Catastrophes, like floods for example, cannot be avoided simply by improvisation. What is required, from a scientific point of view, is detailed knowledge of the phenomenon to be prevented, long-term monitoring programmes, technical ability and a willingness to invest the necessary means.

In recent times, humanity has been threatened by „flooding" of a different nature. We are drowning in an avalanche of waste! This is having a negative effect on the balance of the ecosystems of the atmosphere. Complaining about the situation and cursing the waste will not help! Let us think how we should deal with this problem. Waste, be it huge quantities of domestic waste or industrial waste, has to be disposed of correctly. It can no longer – as has too often been the case in the past – simply be dumped in our countryside.

Chemical waste can be toxic and can represent a threat to the environment for all time. The small quantities of waste from nuclear power plants and nuclear fields of industry and medicine are radioactive. However, the radioactivity decreases continually according to physical laws until the waste is no longer harmful. Waste disposal has to be in a form that protects the biosphere from the damaging effects of toxic or radioactive wastes safely and for long time periods.

The question is not whether we are for or against nuclear power!

Independent of our wishes or influence, radioactivity has been part of Nature for billions of years. People have always lived and evolved in an environment which is naturally radioactive. Natural sources of radiation are active in space, in water, in the air, in the earth ...and even in our own bodies.

The question to be answered is: Can radioactive waste be disposed of safely and permanently in a way which presents no problem for man, animals and plant-life?. Answering this question involves making scientific predictions, predictions which have to cover very long time spans, since the safety of a radioactive waste repository has to be ensured for many thousands and sometimes even hundreds of thousands of years. In order to find a conclusive answer to this question, scientists all over the world have been working for many years: geologists, geophysicists, mathematicians, chemists, biologists...

Faced with these very long timescales, it soon became clear that the reliability of any model of a repository could not be checked purely on the basis of data from laboratory experiments and mathematical calculations. No laboratory programme can simulate the complex facts of Nature over sufficiently long times.

One of the problems with scientific work, laboratory work related to nuclear waste and other fields, is the fact that scientific experiments and studies take place over very short time periods — a long experiment in a chemical laboratory may run a period of a month, two — at the most several years! When you compare this to dealing with geological timescales of ten thousand to one hundred thousand years, it's very difficult to draw a comparison and that's why we look at natural analogues, because natural analogues can take place over thousands, millions or even billions of years.

Let us look at our first natural analogue – **Oklo**. In Africa, in Gabon, the first nuclear reactors ever discovered occurred spontaneously in Nature. Oklo is probably the most famous natural analogue because it is a reactor that went critical 1.9 billion years ago. Oklo is a very old and rich uranium deposit which formed in a sedimentary basin some 2 billion years ago. The reactors were active on average up to 500,000 years, consuming at least 10 tonnes of U-235 and producing a range of waste products (including plutonium, caesium, strontium, etc.).

Oklo is of utmost importance for our natural analogue studies because it is the only area where one can actually look at the fission endproducts and how they have migrated since criticality, so it is of more direct relevance to radioactive waste disposal perhaps than some of the other natural analogues we have been looking at.

Radionuclides which were produced, for example plutonium, neptunium and thorium, have either remained immobilised in situ incorporated in the uranium oxide or have migrated only very short distances into the surrounding rock.

The studies of the Oklo natural analogue thus provide much convincing evidence: **Radioactivity is a common natural phenomenon. Even nuclear energy has been generated by natural nuclear chain reactions.**

Now let us jump from Africa to Spain. At the 5th Natural Analogues Working Group Meeting, 5-9th October 1992, in Toledo, various participants were asked the following question: Which particular natural analogue study do you feel most convincingly demonstrates the future of repositories?

One of the answers was: „Well, I don't think that any one particular natural analogue system demonstrates or can demonstrate the future of repositories. We would like to see a range of different natural systems studied in order to look at the various questions which have to be answered for public health and safety."

Two particular natural analogues have been studied in Brazil, in the vicinity of **Poços de Caldas**. The hill of „**Morro do Ferro**" bears the name „hill of iron" and is one of the most radioactive places in the world. This hill still has some 30,000 tonnes of thorium ore and 50,000 tonnes of rare earth elements quite close to the surface. The plants growing on top of the ore deposit have absorbed so much radium-228 that they leave behind a radiographic image when simply laid on top of X-ray film.

„Morro do Ferro was included in our studies because it offered a good opportunity to study the groundwater mobilisation and migration of thorium and the rare earths. ...This was a key piece in our natural analogues puzzle."

„Hundreds of water samples were analysed over a 21/2 year period. The results show that the **mobilisation rate of thorium from the ore deposit is extremely low**, i.e. less than one billionth of the thorium per year is mobilised and removed by groundwater. This means that the concentration of this radionuclide is 20 times lower in the water flowing through this „hot spot" than the permissible concentration in drinking-water in the United States!"

The Poços de Caldas project had still more important contributions to make. The open-pit **Osamu Utsumi uranium mine** is shaped like an amphitheatre, with a diameter of around 800 m at its widest point. Numerous fractures in the rock walls allow water rich in atmospheric oxygen to penetrate the rock mass and enter into a chemical reaction process, namely oxidation, with the different minerals. This produced the so-called redox fronts which are clearly pronounced in the Osamu Utsumi mine and are an important aspect of the study of this natural analogue. Movement of these redox fronts into the rock continues as long as oxidising infiltration water is available. Movement of the front slows down parallel with consumption of the oxygen in the oxidation process.

What does all this have to do with safe disposal of radioactive waste?

In an engineered repository, oxygen produced by radiolysis, i.e. oxygen produced particularly by the effect of alpha radiation on the water in contact with the metal canisters, could penetrate as far as the engineered barriers and form a redox front at the boundary between the canisters and the isolation material. This means that the knowledge we have obtained from our studies at the mine will provide very important information for the development of repository models.

The most important and most encouraging results of the Osamu Utsumi project are the data which indicate the immobility of many radionuclides and trace elements. The results show that redox fronts act as „element traps". The chemical processes occurring at a front cause mineralogical alterations which generally **slow down the migration of nuclides and fix them by lowering solubility limits**.

Cigar Lake: The search for a more comprehensive understanding of the system led to an investigation of the Cigar Lake natural analogue, which demonstrates the complete interaction of a multi-barrier disposal system. In the north of Canada, near Cigar Lake in the province of Saskatchewan, prospectors discovered a 1.3 billion year old uranium ore deposit. The uranium ore deposit at Cigar Lake is the largest and the richest in the world. The radiation levels are so high that the ore can be worked only fully automatically and by remote-control. What is unusual about this natural analogue?

What is most interesting is that, despite the fact that the largest and richest uranium ore deposit in the world is located here at a depth of only 430 metres, there is no trace of radioactivity to be found at the earth's surface or in the water of the lakes in the area. And the fact that there is no surface expression is very good evidence that this uranium has remained in place since it formed 1.3 billion years ago.

The fact that there is no trace of radioactivity at the surface or in the water allows important conclusions to be drawn with regard to planned radioactive waste repositories:

At Cigar Lake, the **combination of several different natural barriers is so effective that no toxic elements have reached the biosphere in more than 1 billion years**. If radioactive waste were to be disposed of at a similar depth and in similar geological formations, then only very small amounts of radionuclides, or even none at all, would be expected to escape by diffusion. These potential small amounts could be retarded by additional safety barriers until such time as they decay to levels where they are no longer harmful.

Movement of radionuclides in different types of rock and in groundwater has been investigated using natural analogues. Today we know that results are more reliable if the source of the radionuclides can be characterised precisely and, on the other hand, if the time span during which the radionuclides have been mobile can be measured.

Loch Lomond: The sediment bed of Loch Lomond in Scotland fulfils both of the conditions mentioned: the source of the radionuclides is known, as is the time span of mobilisation. The bed of the loch is composed of clayey sediment layers. Scientists have studied the loch in detail. Loch Lomond was selected because of its unusual evolution over the last ten thousand years. The loch was originally freshwater. However, over a period of 1500 years, Loch Lomond was filled with seawater due to a change in sea-level following the end of the last ice age. The sea-level then changed once again. Loch Lomond, fed by rainwater, water from streams and rivers and from the Dubh Loch, once again became a freshwater loch, which it has remained for the last 5000 years.

The computer simulation explains why, through successive changes in sea-level, the bed of the loch consists today of two freshwater layers, between which there is a sediment layer of marine origin. It was assumed that the freshwater layers and the marine layer would differ in terms of chemistry and geology. This hypothesis proved to be correct.

We investigated whether elements such as natural uranium, radium, iodine and bromine were able to migrate from the marine sediment layer into the neighbouring freshwater layers over the last 5400 years. Over this long time period since the marine layer formed, the system has remained stable. The Loch Lomond study provided evidence that the natural elements (analogous to radionuclides) contained in the marine sediment layer, even highly mobile iodine, have not moved significantly in five thousand years. **The excellent isolation capability of clay has been demonstrated.**

Engineered barriers: In the model concept of a repository, massive barriers provided by Nature – deep-lying stable dry rock formations and clay masses – are combined with a series of additional engineered barriers such as glass, cement, concrete, steel and copper. All these materials are exposed to the ravages of time. Corrosion attacks metal and slowly destroys it. Laboratory experiments over restricted time periods provide information which has to be supplemented with natural analogue studies. Only then can reliable long-term predictions be made.

Archaeological findings, the age of which can be determined accurately, are of assistance in this respect.

Near Inchtuthil in Scotland more than 1 million Roman nails were covered with a layer of soil 2 metres thick. They were found during excavations of the camp-site by a team of archaeologists. Investigations showed that only the outer layer of nails was corroded. The bulk of the Roman nails, protected from oxygen and water by the soil and a layer of rust, remained in good condition for two thousand years.

A Swedish warship provided a similar example. In 1676, the Swedish warship Kronan exploded and sank. Archaeologists recovered cannon from the Kronan after they had been partly buried in the sea bed for around 300 years. The alloy of which the cannon are made consists of 95% copper. The muds of the sea bed largely protected this copper alloy from corrosion. It was calculated that, under these conditions, the loss of copper was only 15 microns in 300 years. Based on these calculations, canisters for radioactive waste can be constructed which will resist corrosion for the required time period.

Cement and concrete walls and shafts are encountered in most repository plans. For this reason it is important to find out how long cement mortars can withstand the ravages of time. Huge constructions have survived thousands of years from the times of the Roman Empire. For example, the famous Pantheon in Rome and Hadrian's Wall in the north of England.

Dunarobba: In 1980, a fascinating discovery was made in a clay pit near Dunarobba in central Umbria, Italy. The workers in the clay pit first came across a huge upright tree-trunk followed by more remains of these giant trees. Finally, more than 60 upright tree-trunks have been excavated from the clay layers. These Sequoia trees were buried beneath the clay some 1.5 million years ago and were so well isolated by this clay formation that the wood did not decay and fossilize, but retained the actual structure of wood.

Fossil forests are, of course, not unusual. The fascinating aspect of Dunarobba is that these massive trees are not fossils. They are still composed of wood that can be chopped, sawn and burned, more than a million years after the trees succumbed to the rapid changes of their environment. Scientists are now studying them intently to find out how the clays in which they are buried have been able so effectively to preserve their original nature. **The capacity of clays to isolate** and preserve items buried within them for periods many tens of times longer than the existence of human beings **has been demonstrated at Dunarobba in a most fascinating manner**.

Conclusions: Demonstrating that radioactive waste can be disposed of safely is a unique challenge. In no other field of science or technology has the attempt been made to make predictions over such long timescales. Solutions for the future are often locked in the memories of the stones and in the treasures which they have concealed over geological time spans. We must seek these solutions with perseverance and patience if our planet is to survive in harmony with Nature. **If Man is prepared to learn from Nature then he will have come a significant step closer to realising his dream since time immemorial – being able to predict the future reliably.**

End of the video.