Oklo – A Nuclear Reactor 1800 Million Years Ago

by Dr. S. Eklund, Director General

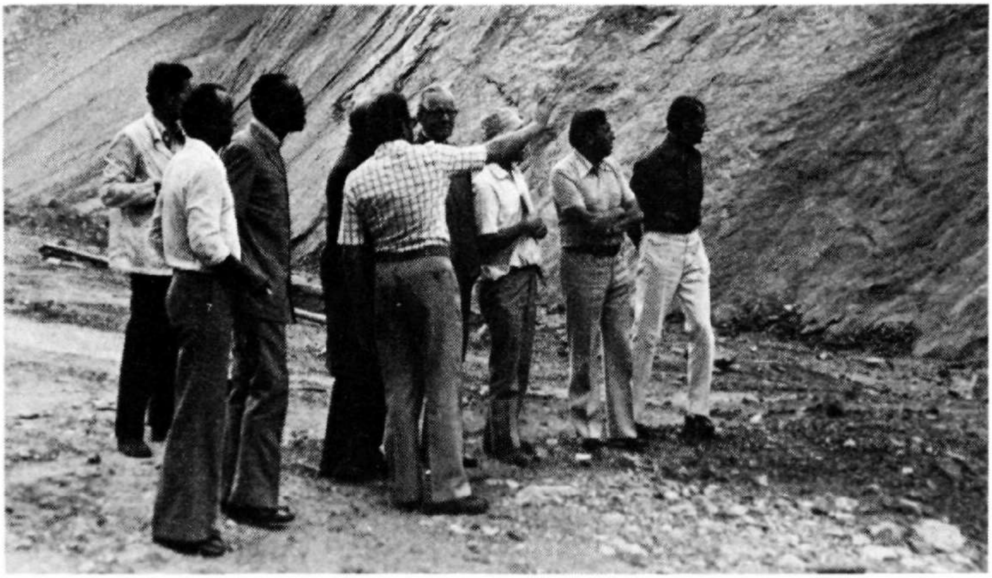
A scientific conference about the so-called OKLO- phenomenon will take place in Gabon in West Africa from 23–27 June this year. The conference is arranged jointly by the International Atomic Energy Agency, the Gabonese authorities and the French Atomic Energy Commission (CEA). As the OKLO phenomenon, named after a uranium mine in Gabon, does not seem to be known outside specialist circles, it may be of interest to report on a few details about this discovery and the interesting conclusions that have been drawn about what happened during a short period of 100–500 000 years, in the earth's development 1 800 million years ago.

Natural uranium contains 0.7202% of uranium-235, the fissionable isotope contained in nuclear fuel. Until June 1972 this concentration had been found to be the same for all uranium that had been discovered until that time, regardless of the place of discovery, and the same concentration was encountered in the uranium of which traces have been found on the moon. In the French gaseous diffusion plant for enrichment of the isotope-235 at Pierrelatte, regular measurements are carried out on the concentration of uranium-235 in the uranium with which the plant is supplied. This is done primarily to ensure that the contained uranium really is of natural origin and does not come from a plant where some fraction of the uranium-235 has already been used. In the course of one such isotopic analysis it was found that the uranium-235 concentration was slightly less than what one would expect from natural uranium, namely 0.7171% instead of the value just mentioned.

If the scientists at Pierrelatte had not made a point of being so careful they might have overlooked this result. However, they carried out a series of checks and discovered that it was not a question of measurement error, but that they were dealing with uranium which had a composition differing from that of "normal" uranium, with additional variations between different samples. It was soon established that the uranium had come from Gabon – or more precisely from a mine, OKLO, in the vicinity of Franceville in south-east Gabon.

The geological formation in which the uraniferous deposits being exploited at Oklo occur is known as the Francevillian. This is a sedimentary series contained within the middle pre-Cambrian basin which covers an area of about 35 000 square kilometres in Gabon. It overlies a crystalline base along the contact with which several uraniferous lodes have been found. The uranium in these lodes may have been derived from leaching of the basement rocks. Dating measurements indicate an age of 1 740 ± 20 million years. The exploitation of the Oklo deposit is carried out by a Gabonese firm, "La Compagnie des Mines d'Uranium de Franceville (COMUF)", with the participation of French capital.

As early as the beginning of August 1972 the idea was put forward that the depletion in uranium-235 had been caused by a chain reaction a long time ago, and in September 1972 this theory was announced together with preliminary research results both in the French Academy of Science and at the General Conference of the IAEA.



Standing at the foot of the Oklo mine in Gabon, the Director General (fourth from right) looks at the site of the so-called Oklo Phenomenon, which he visited in preparation of the June conference on this subject.

The thorough geological and mineralogical investigations which have been carried out since then indicate that a total of about 500 tons of uranium exhibit abnormally low concentrations of uranium-235, with an average concentration of 0.62%. A high total concentration of uranium in a mineral vein corresponds to a substantial reduction in the uranium-235 concentration if the vein is not very limited, in which case the depletion is less pronounced. In one case, a sample had a uranium-235 concentration of only 0.296%. It was concluded by various methods that the uranium in OKLO is about 1 800 million years old. As the half-life of uranium-235 is about seven times shorter than that of uranium-238, namely 700 million years, this means that the uranium-237 concentration about 2 000 million years ago was much higher relative to that of uranium-238 – over 3% instead of the 0.7% which has hitherto always (with the exception of OKLO) been found to be the case. The local high concentration of uranium, an "enrichment" to over 3%, the absence of strongly neutron absorbing materials and the presence of water as a moderator – these four circumstances led, 1 800 million years ago, to chain reactions in certain parts of the mine, in which a total energy of about 10 000 MW years was probably generated over a period of some hundreds of thousands of years.

The detailed investigations which have been made of the OKLO phenomenon are an interesting example of how nuclear physics methods are now being used in geology and geochronology. For age determination, use is made, inter alia, of the uranium-lead method, which is based on the fact that the radioactive decays of uranium-238 and 235 lead to two isotopes of lead. The chain reaction in uranium gives rise to fission products which are highly radioactive in a modern power reactor, but which at OKLO have decayed in the course of millions of years to stable non-radioactive products, which can be identified mass spectrometrically on the basis of their isotopic composition.

One conclusion which can be drawn from these measurements is that there are very few fission products from plutonium. Since the half-life of plutonium is 24 000 years this indicates that the chain reaction proceeded very slowly, so that the plutonium which was formed in the OKLO reactor during the reaction decayed before it could take part in the fission process. Moreover, consideration of heat transport from the sites where the reaction occurred leads to the conclusion that the reaction must have lasted at least 100 000 years.

Another fundamental question is how a stable equilibrium could have been maintained at the places where the reaction occurred for a time as long as this. It is one thing to imagine that under certain circumstances criticality was achieved within a certain area and another thing to imagine what control mechanisms existed, and not only regulated the reaction momentarily but also functioned for the hundreds of thousands of years we are considering here.

The assumption which appears to be best supported by the results of the investigations is that the reactivity was regulated both through the presence of neutron-absorbing materials which were gradually used up (the same method is employed in our present power reactors) and through variations of the amount of water in the uranium ore with the power development in the reaction.

Thanks to fortunate circumstances, when the OKLO phenomenon was discovered, although about half of the uranium had already been mined, the sites of the chain reactions which had taken place could still be identified. If the discovery had been made 40 years ago, before the discovery of the uranium fission in 1938, it would probably have been considered merely as a scientific curiosity. However, the extensive knowledge which has been gained of the physics and chemistry of uranium fission was meanwhile available, and it was therefore possible to embark upon an analysis of the existing fission products. One has to admire the French scientists representing different disciplines both within and outside the CEA, who, together with the Gabonese authorities, carried out an extraordinarily comprehensive investigation in such a short time, and thereby arrived at a first interpretation of the text on an interesting page in the world's history.

Exploitation of the deposit will continue (about 500 tons of uranium a year). It is very much to be hoped that, despite inconveniences to the normal operation of the mine arising out of the preservation of these fossil reactors, at least major parts of the areas where the reactor sites are to be found will be preserved. Because of formal and financial difficulties after the end of the war it was not considered possible to conserve as a historic monument the reactor which was started up in Chicago in 1942 with natural uranium in a graphite moderator. Its natural predecessor, the fossil reactor in OKLO, should not suffer the same fate.

The African and the South American continents were separated no more than about one hundred million years ago. It will be interesting to see whether a corresponding discovery will be made in future in some of Brazil's uranium mines. The author of these lines had the opportunity to visit the OKLO mine a few months ago. It is a great experience to visit the place where Nature itself started a process which homo sapiens managed to reproduce only 1 800 million years later!

It is perhaps appropriate to emphasize that, in this time of concern regarding the commercial expansion of nuclear power, there is no risk that the OKLO process will recur in any other mine. The concentration of U-235 has, in the course of millions of years, decreased too far.