Environmental considerations may turn out to be the dominant factor in determining the role to be assumed by ionizing radiation in our industrialized world. The energy required to cure coatings with electrons is 7% of that required with heat. The energy required to sterilize food with electrons or gammas is far less than that required with heat. As the competition for clean fuels increases, the cost of energy may prove to be the dominant cost. A detailed analysis of total energy expenditures is needed to determine whether it will benefit our society to place strong emphasis on energy conservation by widespread substitution of electron beam processes for thermal processes. It is with such a challenge that I finish.

The future looks bright and rewarding. The present isn't too bad, either. It's about time.

The Oklo Phenomenon

by Roger Naudet*

Subject of an International IAEA-Symposium from 23 to 27 June 1975

During 1972, research workers of the French Commissariat à l'Energie Atomique made an astonishing discovery: fission chain reactions had been triggered spontaneously in the very remote past within a uranium deposit in Gabon and parts of the deposit had behaved like a modern nuclear reactor for hundreds of thousands of years. Subsequent investigations showed that the reaction sites had remained in a remarkable state of preservation, so that detailed study was possible.

The IAEA felt that the Oklo phenomenon would be an excellent subject for international co-operation in fundamental research and agreed to the suggestion of the Gabon Government and the French Commissariat à l'Energie Atomique that a jointly organized symposium be held. The symposium will take place at Franceville, Gabon, from 23 to 27 June 1975.

It is a familiar fact that, of the two principal isotopes of uranium, which are naturally radioactive, ^{235}U has a shorter half-life than ^{238}U (7.1×10^8 years as against 4.51×10^9 years). Consequently, the concentration of ^{235}U in natural uranium is decreasing constantly with time; in the very remote past it was much higher than it is now (3.65% two thousand million years ago as against 0.72% now).

A "FOSSILIZED" NUCLEAR REACTOR

It was therefore suggested some time ago that fission chain reactions might have been triggered spontaneously within uranium deposits in the very remote past, given the existence of certain conditions: high concentrations of uranium; the absence of strongly neutron-absorbing elements; and the presence of water. It did not seem out of the question

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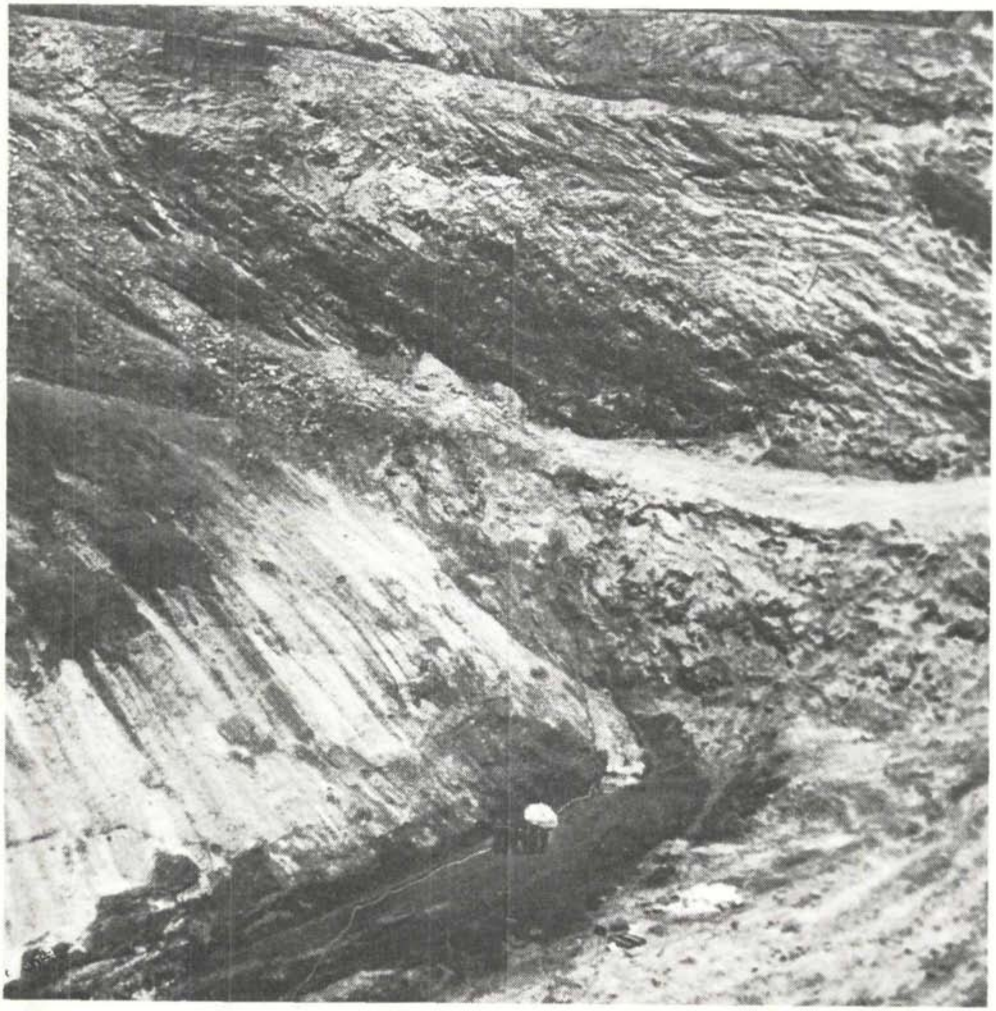

The quarry of Oklo, Gabon. In front the area with the natural reactors. Photo: C.E.A.

that these conditions should exist together, the probability of their existing together being greater the further one went back in time.

The idea was not taken very seriously, however, for the following reason. Even if such phenomena had occurred and even if in some cases there had been mechanisms permitting the reactions to continue until the isotopic composition of the uranium had changed significantly, what would be the chances of finding any traces? Since those remote times – one is thinking in terms of thousands of millions of years – the Earth's surface had undergone repeated upheavals; moreover, uranium was an element which moved about readily when there was circulating water present, so that most uranium deposits would have been considerably modified over the ages. An unlikely conjunction of circumstances would therefore be necessary if one was to find a "fossilized" nuclear reactor, as it were, from those distant days in the Earth's history. But that is precisely what has been found within the Oklo uranium deposit.

THE STORY OF THE DISCOVERY

The story of the discovery is worth recalling. It began with the observation of a very slight isotopic anomaly in a natural uranium sample during a routine analysis at the Pierrelatte laboratory. A series of checks was carried out with a view to getting to the bottom of the matter. Then, when these had revealed other anomalous samples, a systematic programme of analyses was started, the aim being to find the origin of what was thought to be some kind of artificial contamination. It was discovered that uranium ore with a concentration of fissionable nuclei below the normal had been received from Gabon, and inquiries revealed that it came from the northern end of the Oklo deposit. In addition, it was found that very large amounts of the depleted ore had already been supplied to the nuclear industry.

Investigations revealed abnormal uranium in debris resulting from earlier exploration in the suspect area, and this was studied with great care. Fission products discovered in the ore pointed clearly to the origin of the anomaly.

It was decided, accordingly, that the part of the deposit yielding anomalous uranium should be reserved for scientific research and that exploitation in that zone should cease. In unworked regions of the deposit, exploration brought to light very large, still intact parts of the reaction sites. These have been studied in detail through boreholes and a great deal of sampling has been done.

A VERY HIGH URANIUM CONCENTRATION

The reaction sites consists of several compact bodies of uranium ore with a very high uranium concentration. Altogether, over 500 tons of uranium took part in the reactions (perhaps even more, for fresh ore bodies have just been discovered). The energy released must have amounted to almost 10^{11} kWh. At some points the integrated neutron flux exceeded 1.5×10^{21} n/cm^2, and samples with a ^{235}U concentration of as little as 0.29% (as compared with 0.72% in natural uranium of normal isotopic composition) have been found. For such values to be attained, there must have been extremely effective mechanisms for controlling the nuclear reactions, mechanisms which have not yet been fully elucidated.

Even more remarkable is the state of preservation of these "fossilized nuclear reactors"; in fact the uranium has retained its configuration from the time of the reactions so faithfully that the reaction rate distributions through the ground can be interpreted in terms of neutron physics. This implies a quite exceptional conjunction of circumstances, and it is expected to be possible to reconstruct the progress of the phenomenon in some detail.

Thanks to the innumerable "traceurs" resulting from the nuclear reactions, it is possible to study a whole episode in geological history extending from the deposition of these very heavy concentrations of uranium about 1800 million years ago to quite recent modifications. Besides its intrinsic interest, such a study may provide much information of practical value.