Oklo Natural Nuclear Reactor

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Outline

• Before Oklo
• Discovery of the Oklo anomaly
• Explanation of anomaly
• Operation of Oklo
• Implications of Oklo research

Aerial view of the Oklo open mine pit in Gabon, Africa.
Before Oklo

• **(1942)** Chicago Pile goes online, and is self-sustaining.

• **(1953)** George W. Wetherill & Mark Inghram find evidence of neutron induced fission in a Congo pitchblende.

• **(1956)** A chemist by the name Kuroda sketches out the requirements necessary for natural nuclear fission.

• From 1957 until mid 1973 no known natural fission detected.
Kuroda’s Requirement

- **Quantity**: Abundance of fissile uranium $^{235}$U isotope.
- **Size**: Uranium deposit should exceed the average length that fission-inducing neutrons travel ($\sim 2/3$ meter).
- **Moderator**: Neutron moderator, a substance that can slow down neutrons produced through fission.
- **Lack of poisons**: Elements that absorb neutrons should not be present (boron, lithium, etc).

![Graph showing isotopic amount of $^{235}$U as a function of millions of years ago](image)

<table>
<thead>
<tr>
<th>Uranium Isotope</th>
<th>Absorption cross section</th>
</tr>
</thead>
<tbody>
<tr>
<td>U-235</td>
<td>680.9 barns</td>
</tr>
</tbody>
</table>

Reported cross section for uranium-235 [2]
Oklo Anomaly

• French uranium enrichment center detects anomaly in isotopic ratio for UF$_6$.

• Analysis reveals isotopic abundance of $^{235}\text{U}$ in sample core from Gabon is 0.6000% instead of 0.7202%.\[^3\]
  • Corresponds to approximately 200 kilograms of missing $^{235}\text{U}$.

\[
\begin{array}{|c|c|}
\hline
\text{Isotope} & \text{Abundance} \\
\hline
^{238}\text{U} & 99.2744 \\
^{235}\text{U} & 0.7202 \\
^{234}\text{U} & 0.0054 \\
\hline
\end{array}
\]

Percent present day abundances of common uranium isotopes \[^4\]
Explanation of Oklo Anomaly

• CEA and International Atomic Energy Agency form committee for investigation.

• Analysis of fission products in Oklo ores confirms natural nuclear reaction occurred approx. 2 billion years ago.
  • Telltale products:
    • Neodymium-144 & -145
    • Thorium-232
    • Bismuth

Fission of a nucleus of $^{235}$U [5]
Operation of Oklo

- Isotopic analysis of xenon proposed by Kuroda.
- Analysis performed by Meshik et al. found abundance of xenon-131 & 132 isotopes in aluminum phosphates.
- Confirmed self-regulating pulsed operation
  - Time “on” ~30 minutes
  - Time “off” ~2.5 hours
Operation of Oklo
Operation of Oklo

• Total energy released was approximately 15,000 megawatt-years, with an average power output of less than 100 kilowatts. [7]

• Operation of this nature continued between 100-300 thousand years without any meltdowns or uncontrolled nuclear reaction leading to an explosion. [7]
Implications of Oklo research

• Oklo data allows for the research into possible shifts in fundamental constants of nature such as the fine structure constant.
  • Investigate the cross section of neutron capture for samarium-149 [6]

• Demonstrates a way to store nuclear waste by use of aluminum phosphates.
Questions?
Refs.


Backup 1

• Fission Products of Uranium-235.

Backup 2

- Decay of fission products:
  - $\text{I} - 132 \rightarrow \beta^-$ \rightarrow $\text{Xe} - 132$
    - Likewise for $\text{I} - 131, \text{I} - 133, \text{I} - 134, \text{I} - 136$
    - Decay time, respectively: 8 days, 2 hours, 20 hours, 52 minutes, 80 seconds
Geology of Gabon

1. Nuclear reactor zones
2. Sandstone
3. Uranium ore layer
4. Granite

https://en.wikipedia.org/wiki/Natural_nuclear_fission_reactor#/media/File:Gabon_Geology_Oklo.svg