Prehistoric Nuclear Reactors?

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Outline

Review of U238 & U235 Fission:

Fast neutrons induce U238 fission, but that releases no replacement neutrons

Slow neutrons induce U235 fission, which **does** release new neutrons, but they're fast

Before they can chain react with more U235, they must be slowed down ("moderated")

If moderator is water, need > 3% U235 (in U238) to sustain chain reaction

From half-lives: U235 would have exceeded that abundance > 1.7 billion years ago

The alarming data, that was then reinterpreted as evidence for such reactors in Africa

How they likely formed:

Water flow concentrated Uranium by first dissolving, then re-depositing, its oxides

But for those oxides to form, there had to be a lot of oxygen in earth's atmosphere

Oxygen which was only liberated by spread of cellular life on earth

Before 1.7 billion years ago: Not enough life => Not enough O_2 => No natural reactors

But with life, geology suggests reactors pulsed on-and-off for hundreds of thousands of years!

(Written / Revised: August 2017)

Prehistoric Nuclear Reactors?

Could **GEOLOGY** ever produce a naturally occurring nuclear reactor?

Scientists believe this MIGHT have occurred

Long long ago . . . right here on Earth

The explanation comes right out of my preceding lecture:

Nuclear Power – But they blow up!

So I just had to share this fascinating story

Ideally, you should review the first half of that preceding lecture

But, in case you're in a hurry, I'll provide a quick review:

On earth, uranium now has TWO significant isotopes:

Uranium 238 (^{238}U):

It makes up 99.27% of the earth's current supply of uranium

It spontaneously falls apart, but extremely slowly: "half-life" = 4.6 billion years

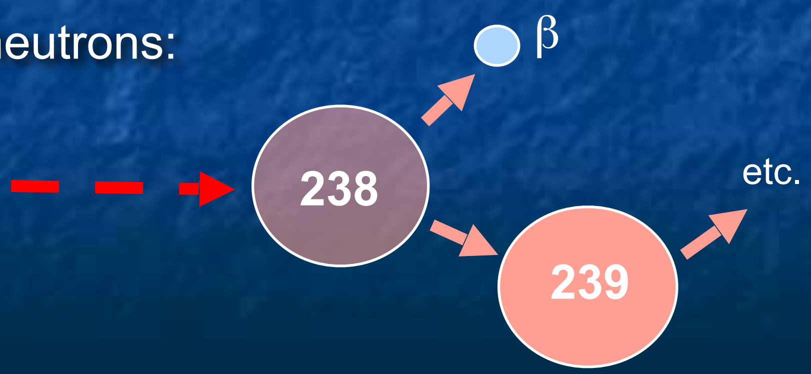
But if a **^{238}U** atom is struck by a **fast** (high kinetic energy) neutron:

It tends to absorb that fast neutron

But it then becomes extremely unstable

And most quickly fall to pieces

But none of those pieces are free/lone neutrons:



The second significant uranium isotope is:

Uranium 235 (^{235}U):

It makes up 0.72% of the earth's current supply of uranium

It spontaneously falls apart a bit more quickly: "half-life" = 703.8 million years

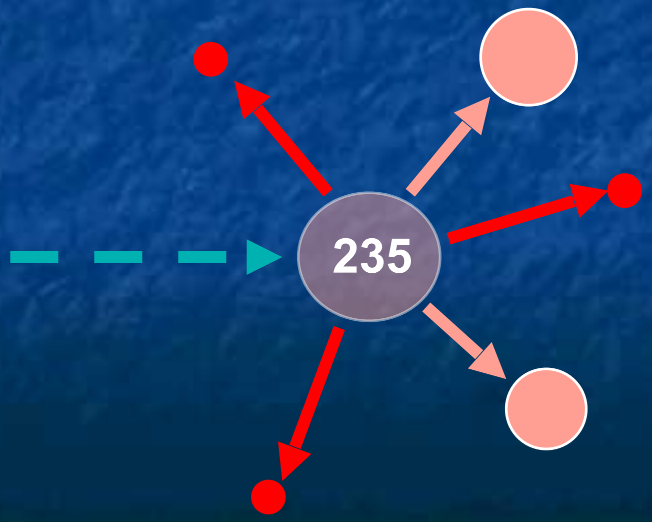
But if a **^{235}U** atom is struck by a **slow** (low kinetic energy) neutron:

It tends absorb that slow neutron

But it then also becomes extremely unstable

And most quickly fall to pieces

But **its** pieces include 1-3 fast neutrons:



But neutrons, of any speed, aren't usually flying around

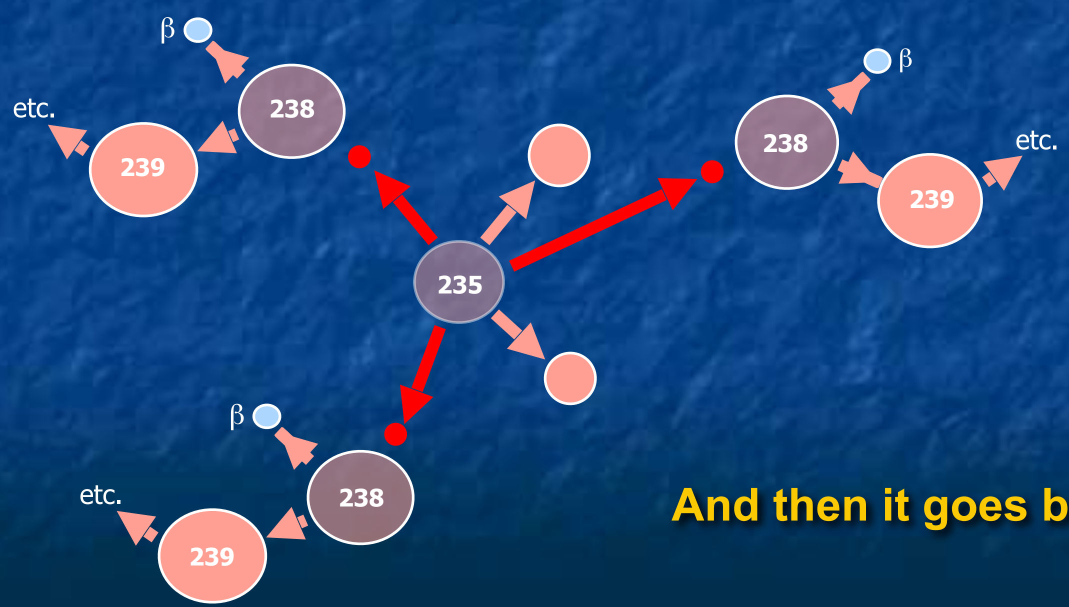
So it's normally extremely boring:

After 4.6 billion years, half of the ^{238}**U** atoms will have fallen apart

After 704 million years, half of the ^{235}**U** atoms will have fallen apart

But when a ^{235}**U** DOES fall apart, it can get briefly exciting

because its liberated **hot neutrons** can cause 1-3 ^{238}**U's to fall apart**



And then it goes back to being extremely boring

UNLESS there is some **water** *hanging around!*

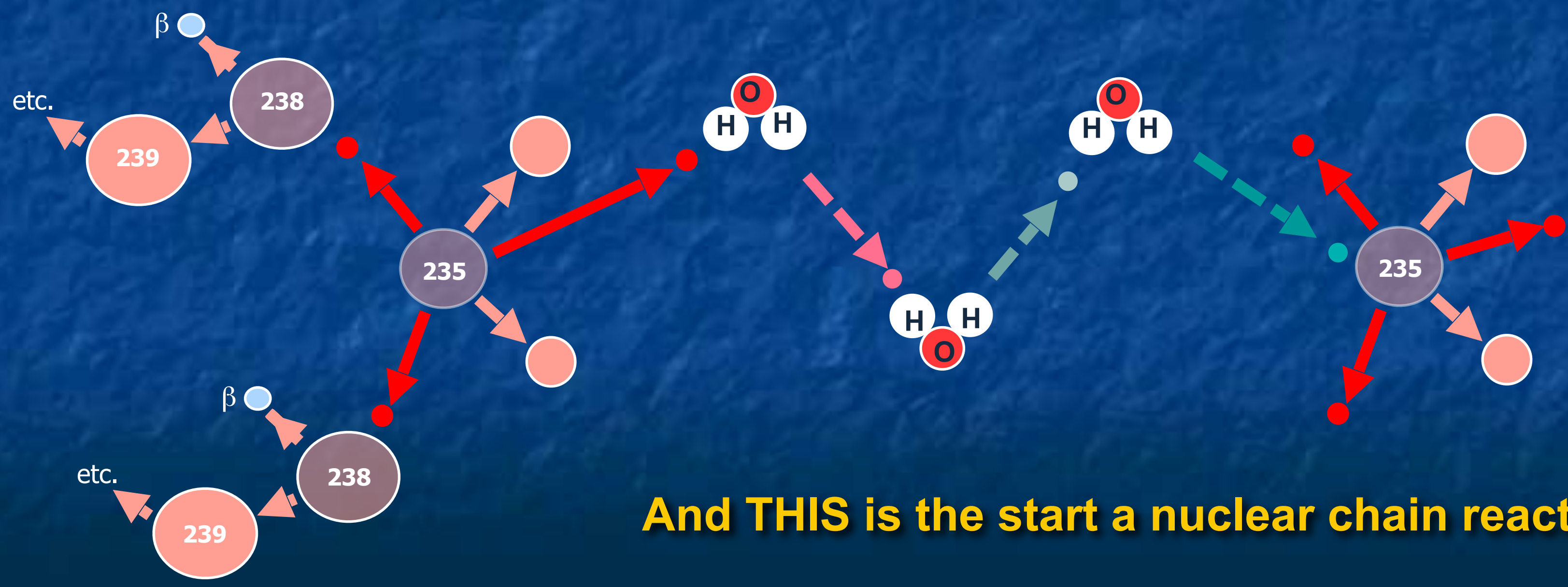
Then, a **fast "hot"** neutron can bounce off water's H atoms

Which, because H has about the same mass, will be kicked aside

taking away some of the incident neutron's kinetic energy

After multiple collisions, a **fast "hot"** neutron thus becomes a **slow "cool"** neutron

Which can THEN cause **another ^{235}U to fall apart**



And THIS is the start a nuclear chain reaction!

The environment of a nuclear reactor promotes this chain reaction

But nuclear reactors also require:

That the uranium atoms are packed rather tightly together

Thus oxides of ^{235}U and ^{238}U are refined and compressed inside fuel rods

And light-water moderated nuclear reactors additionally require:

That the ^{235}U concentration must be jacked up from 0.72% to 3-5%

Difficult because ALL uranium atoms have the same number of electrons

So they bond to the same things ruling out "chemical" purification

Nuclear enrichment plants thus use exotic "gas-diffusion" or "ultra-centrifuges"

As first developed for bomb manufacture in the World War II Manhattan Project

But those bombs required **much more intense** ^{235}U enrichment

To levels of ≥ 80% 235U (rather than just 3-5%)

End of Review / Back to possible "prehistoric nuclear reactors"

Here we need to reflect on what a "radioactive half-life" really implies:

^{235}**U** half life = 703.8 million years vs. ^{238}**U** half life = 4.6 billion years

Right now, for every **9927** ^{238}**U's,** there are **72** ^{235}**U's** (from: 99.27% vs. 0.72%)

But, **1 billion years ago**, the numbers were (based on the meaning of "half-life"):

$^{235}\mathbf{U} = (72) \times 2^{\mathbf{(1\ billion\ /\ 703.8\ million)}} = 192$

^{235}**U** = 1.6%

$^{238}\mathbf{U} = (9927) \times 2^{\mathbf{(1\ billion\ /\ 4.6\ billion)}} = 11{,}541$

And **2 billion years** ago the numbers were:

$^{235}\mathbf{U} = (72) \times 2^{\mathbf{(2\ billion\ /\ 703.8\ million)}} = 516$

^{235}**U** = 3.7%

$^{238}\mathbf{U} = (9927) \times 2^{\mathbf{(2\ billion\ /\ 4.6\ billion)}} = 13{,}418$

So the 3% nuclear chain reaction threshold was met about . . .

1.7 billion years ago:

$^{235}U = (72) \times 2^{(1.7 \text{ billion} / 703.8 \text{ million})} = 384$

$^{235}U = 2.9\%$

$^{238}U = (9927) \times 2^{(1.7 \text{ billion} / 4.6 \text{ billion})} = 12{,}825$

But in the earth's crust uranium atoms are normally way too far apart

So now mix in some **oxygen gas**

Which reacts with uranium to form oxides

Which are somewhat soluble in **water**

THEN, **flowing water** can pick up both ^{235}U and ^{238}U ("leeching" it from the rocks)

And if that water flow happens to dry up in one place,

it will leave a residue of concentrated ^{235}U and ^{238}U

Which completes the requirements for a **natural** *nuclear reactor*

Scientists recognized this possibility as early as the 1950's

Indeed, one theorist, Paul Kuroda, published a supporting calculation in 1956 [1]

But his paper got largely ignored - Until a French security agency got involved

Why? Because security agencies worry a LOT about missing ^{235}U !

After all, ^{235}U is THE essential ingredient for making a fission nuclear bomb

In 1972, ore from the **"Oklo" Gabon Africa mine** was being processed in France

EVERYWHERE else in the world, uranium ore contains 0.72% ^{235}U

But for Oklo, the concentration was found to be significantly lower [2]

1) On the Nuclear Physical Stability of the Uranium Minerals. Paul Kazuo Kuroda in *Journal of Chemical Physics,* Vol. 25, No. 4, pages 781–782; 1956 (*http://www.nuclearplanet.com/Kuroda%201956.pdf)*

On average, the decrease was small: 0.7202% => 0.7171%. But in selected mine locations it fell as low as 0.44%. See:

2) A Natural Fission Reactor, Scientific American 1976 (*https://www.scientificamerican.com/article/a-natural-fission-reactor/)*

The French Atomic Energy Commission (CEA) was thus called in:

They quickly calculated the total amount of ^{235}U that could be missing from Oklo

They didn't like the answer: Enough to build a half dozen nuclear bombs

But the CEA also knew just how hard it is to selectively remove ^{235}U

And they found no evidence that the Oklo ore had been diverted

through one of the aforementioned **nuclear enrichment plants**

The CEA was thus reportedly "perplexed" [3] for several weeks

Until someone remembered those predictions of natural nuclear reactors

Which provided a much less alarming answer to where the ^{235}U had gone:

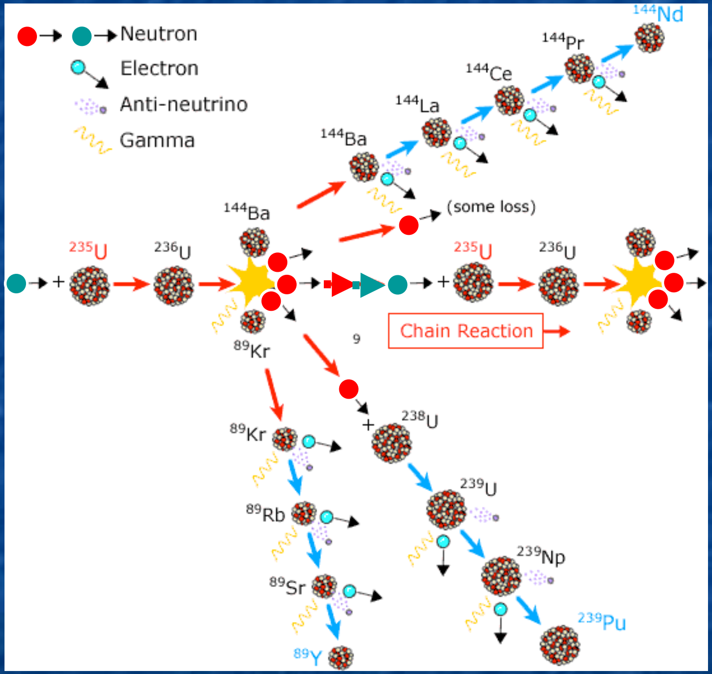
3) The Workings of an Ancient Nuclear Reactor – Scientific American 2009 (https://www.scientificamerican.com/article/ancient-nuclear-reactor/)

It had long ago fissioned away into other things: [2]

The "things" that are produced when atoms fall apart, making other atoms

Otherwise known as the "daughters" produced in nuclear chain reactions

As only **partially** enumerated this figure from my introductory lecture:



My modification of figure found at: http://www.nobelprize.org/educational/physics/energy/fission_2.html

And this all occurred, quite naturally, about 1.7 billion years ago

2) A Natural Fission Reactor, Scientific American 1976 (*https://www.scientificamerican.com/article/a-natural-fission-reactor/)*

That seems to wrap things up & tie it in a bow, right?

NO, there are still some loose ends to be explained:

Tracking radioactive half-lives backward, we calculated historic ^{235}**U** percentages of:

Now:	- $1.0x10^9$ BCE:	-$1.7x10^9$ BCE	-$2x10^9$ BCE
0.72%	1.6%	2.9%	3.7%

Indicating that nuclear chain reactions **could** be sustained 1.7 billion years ago

But, at 3.7%, they would have worked even better 2 billion years ago

And they would have worked **even better** before that . . .

So why say natural nuclear reactions ONLY occurred ~ 1.7 billion years ago?

Because that was about the time life was getting started on earth

*And it took **life** to liberate large amounts of gaseous oxygen*

Which, recall, was essential for doing this:

Oxygen gas reacted with widely dispersed uranium, to form oxides

Those oxides were somewhat water soluble

Allowing **flowing water** to pick up both ^{235}**U** and ^{238}**U**

Which, if it then dried up in one place,

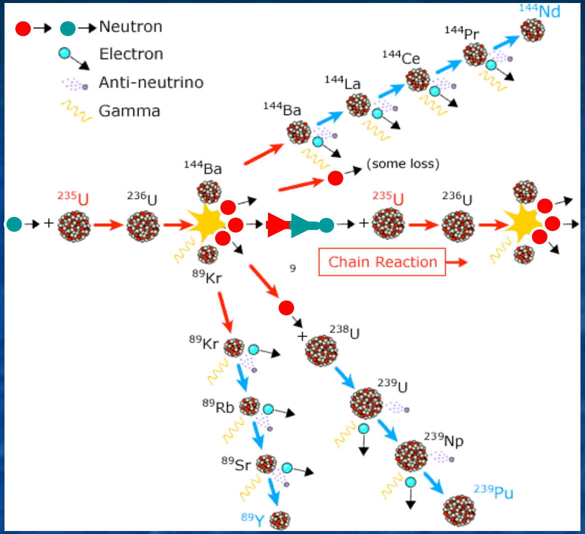
would leave concentrated residues of ^{235}**U** and ^{238}**U**

So, getting even weirder, scientists suggest that prehistoric nuclear reactors

could not be formed **until** oxygen-liberating life began populating the earth

But it gets even **stranger**:

When they carefully analyzed those chain reaction products:



They concluded that these prehistoric reactors fired up 1.7 billion years ago,

and "operated" intermittently for hundreds of thousands of years

But that intermittent operation was not random - reaction products instead suggest:

The chain reaction ran for ~ 30 minutes

It was then extinguished for ~ 2 ½ hours

And then that cycle was repeated over and over and over . . .

All because sustained fission still requires neutron "moderation"

That is, fast/hot neutrons from ^{235}**U** must be transformed into slow/cool neutrons

In manmade nuclear reactors, neutrons do this by ricocheting off liquid water

Prehistoric reactors apparently used the same process

But when those **soggy-stuff-buried-in-the-ground-reactors** (SSBGR)[4] fired up:

That patch of ground would start to get **really hot**

And after ~ 30 minutes, almost all of the liquid water would boil away

Then, deprived of that neutron "moderating" liquid water,

the nuclear chain reaction would be quenched

But THEN the ground would start to cool back down

And after about 2 ½ hours enough liquid water could seep **back in**

that the nuclear chain reaction would start back up!

And so on, and so on, and so on . . .

4) So named by Me

But how did they come up with the exact 30 minute / 2 ½ hour timing?

The ^{235}U / ^{238}U chain reactions are known to release multiple isotopes of Xenon

- Some isotopes are released very early, some are released later

However, as a gas, Xenon doesn't normally stick around

- But at Oklo, hot water slowly oxidized aluminum & silicon-containing minerals
  - Which could trap Xenon, at least if it hung around long enough
- But while late-emerging Xe isotopes were found, early-emerging Xe was not!

Suggesting the ground was VERY hot when the early Xe emerged

- Because extreme heat would pressurize that Xe, driving it out and away

But that the ground was cooler when the late Xe emerged

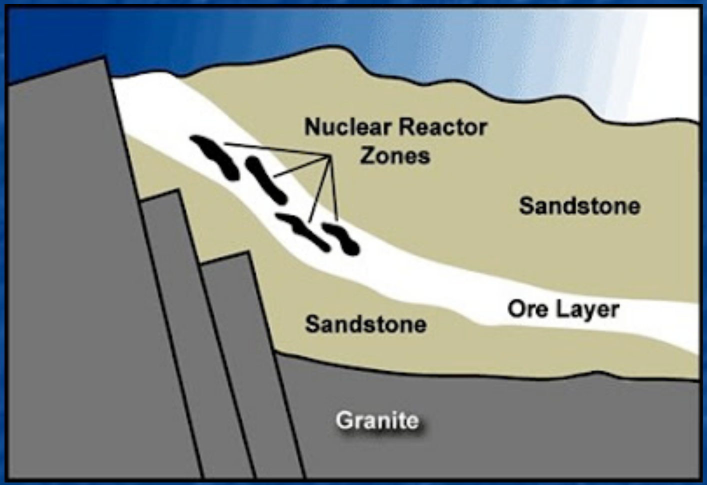
- Allowing it to hang around long enough to be trapped by mineralization

Known timing of Xe generation then indicated: "30 minutes on + 2 ½ hour off" [3, 5]

3) The Workings of an Ancient Nuclear Reactor – Scientific American 2009 (https://www.scientificamerican.com/article/ancient-nuclear-reactor/)

5) Record of Cycling Operation of the Natural Nuclear Reactor in the Oklo/Okelobondo Area in Gabon, Phys. Rev. Lett - 2004 (http://journals.aps.org/prl/abstract/10.1103/PhysRevLett.93.182302)

Leading to remarkably familiar-sounding African Ghost Reactors:



Experts OR particularly observant readers of my introductory nuclear lecture might figure out that I have not really chosen the most appropriate **type** of "ghost reactor" to depict in my figure above.

(HINT: Note type of reactor suggested by figure's reactor containment structure)

top: http://mashable.com/category/nuclear-reactor/ *bottom:http://www.bldgblog.com/2009/10/fossil-reactors/*

Other WeCanFigureThisOut.org note sets on nuclear energy:

Note set introducing nuclear energy & its accidents:

Nuclear Energy – But they blow up!

Note three sets on the possible future of nuclear energy:

Gen III/III+ Reactors: Confronting Cost & Operational Safety

Gen IV Reactors: Two Designs that Might Radically Reduce Nuclear Waste

Other Gen IV Nuclear Reactors

For links to these note sets (and their accompanying resources webpages) visit:

www.WeCanFigureThisOut.org/ENERGY/Energy_home.htm

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This set of notes was authored by John C. Bean who also created all figures not explicitly credited above.