Calculating K–Th–U abundances from ^{21}Ne and ^{39}Ar nucleonic production in the crust and mantle

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Goal

Determine the abundance and distribution of K, Th & U in the Earth (crust and mantle)

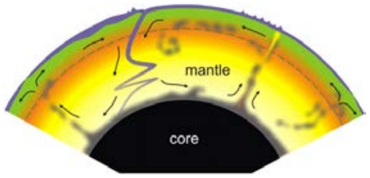
Hot vs. cold Earth?

Method

Compare predictions of nucleogenically produced underground noble gas' isotopic composition to newly available measurements.

Context

Describing the K, Th, and U content of the Earths interior fixes its production of radiogenic heat and thus defines the planets secular cooling history. The planetary energy sources include the primordial gravitational energy liberated upon accretion and core formation, and present-day energy sources due to inner core growth and radiogenic heating. However, unknown is the relative contribution of radiogenic heat production to total energy loss. The stiffness of the core-enveloping, rocky silicate shell and the amount of internal heat generation (i.e., radioactive decay of U, Th, K) control how fast the planet cools.

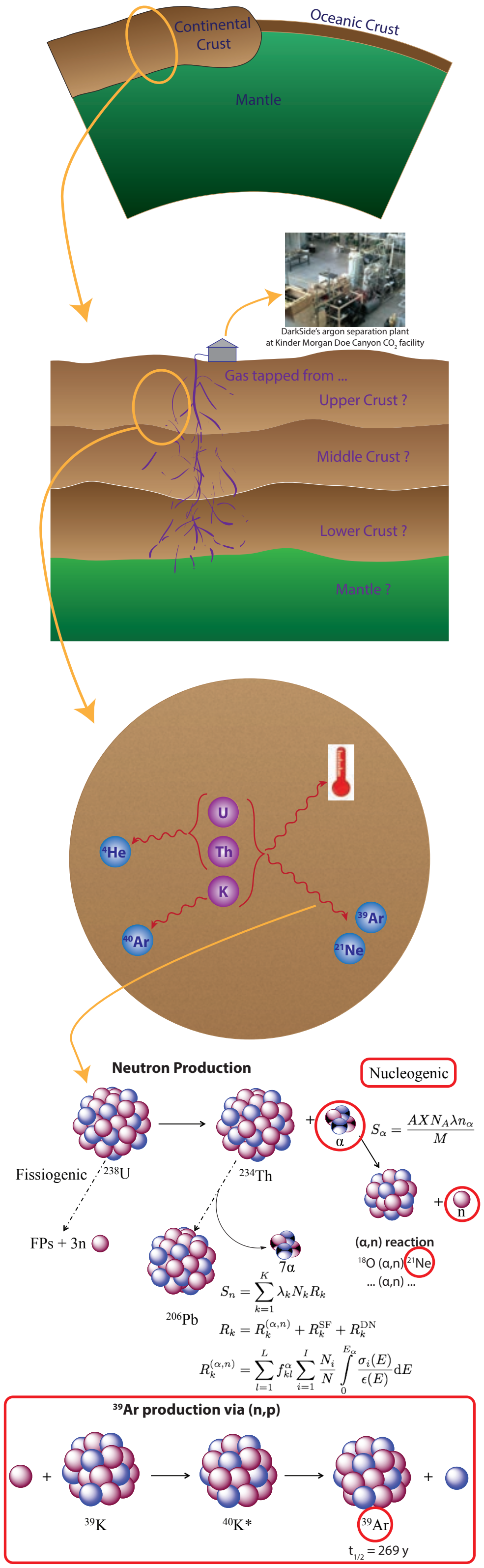


State of Science

Geoneutrino detection describes the U & Th content of the Earth. The mantles flux of ^{40}Ar/^{4}He reflects its integrated K/(U+Th) content, but this ratio is influenced by contributions from vertically separated reservoirs and differential diffusion rates of noble gases. Our efforts seek to produce an independent estimate of K–Th–U in the crust and mantle.

Rationale

Argon detectors for WIMP dark matter searches (i.e., DEAP, DARWIN, ArDM, WARP, DarkSide) require **low-radioactivity argon** (i.e., low ^{39}Ar), and there is ongoing effort in the experimental particle physics community to measure ^{39}Ar in **underground gas sources** [1] . These new measurements – in concert with predictions based on abundance of U, Th, K, and other elements – can be used to constraint the amount of radioactivity in the crust and shallow mantle.



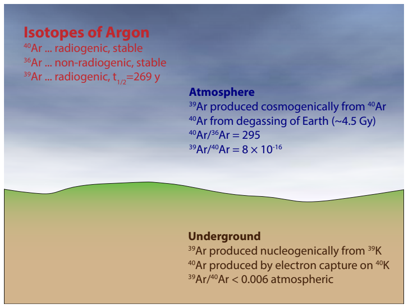


Table 1: *α-particle and ^{40}Ar production rate (# atoms per second per kg of rock) calculated for selected rock compositions.*

Compositional estimate	Elem. abun. Th	U	K	α prod. rate ^{232}Th	^{238}U	Th+U	^{40}Ar prod.
Continental Crust	ppm		%	$kg^{-1}s^{-1}$			$kg^{-1}s^{-1}$
R&G [2] – Upper CC	10.5	2.7	2.3	260	270	533	77
R&G [2] – Middle CC	6.5	1.3	1.9	160	128	290	64
R&G [2] – Lower CC	1.2	0.2	0.51	29	20	50	17
Shallow mantle (DMM)	ppb		ppm	$kg^{-1}s^{-1}$			$kg^{-1}s^{-1}$
Workman and Hart [3]	7.9	3.2	50	0.19	0.32	0.52	0.17
Salters and Stracke [4]	13.7	4.7	60	0.33	0.46	0.82	0.20
Arevalo & McD [5]	46	12	152	1.1	1.2	2.4	0.51

Table 2: *Neutron production rate (per year per kg of rock) evaluated according to Ballentine and Burnard [6] for selected rock compositions.*

Compositional estimate	(n,p) Th	U	fission ^{238}U
Continental Crust	$kg^{-1}yr^{-1}$		$kg^{-1}yr^{-1}$
Rudnick and Gao [2] – Upper	5900	3300	1300
Rudnick and Gao [2] – Middle	3700	1600	620
Rudnick and Gao [2] – Lower	710	260	95

Next steps:

- Calculate ^{39}Ar production by ^{39}K$(n,p)^{39}$Ar.
- Calculate ^{21}Ne production [^{18}O$(\alpha,n)^{21}$Ne].

- The isotopic signature of the deep well gas – ^{39}Ar/^{40}Ar, ^{40}Ar/^{21}Ne, ^{21}Ne/^{4}He – depends on the source rock composition.
- ^{39}Ar production rate proportional to abundances of K × (U+Th)
- ^{40}Ar production rate proportional to K abundance but not U, Th
- ^{21}Ne, ^{4}He production proportional to U+Th abundance

References

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