Instrumentation Development for Planetary in situ $^{40}Ar/^{39}Ar$ Geochronology

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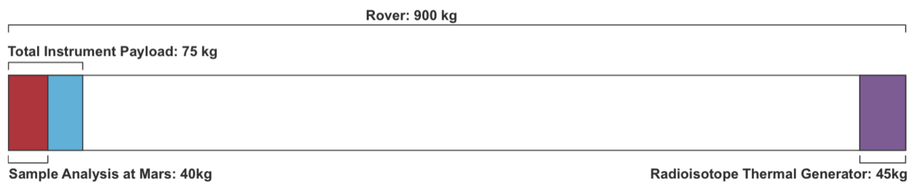
$^{40}Ar/^{39}Ar$ Geochronology: A Primer

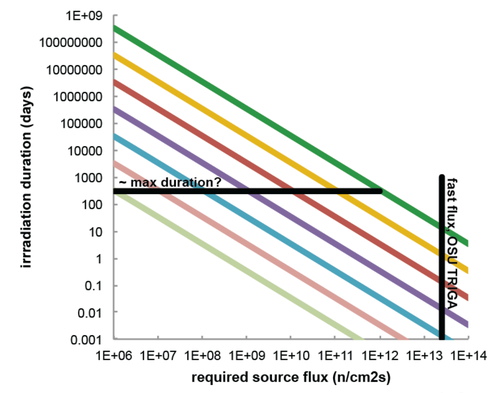
Motivation

A key to understanding the history of planetary and asteroidal bodies is the accurate and precise determination of the timescale over which they developed. Although absolute dating of planetary materials remains a primary goal of planetary research, sample return missions from key Solar System sites remain a distant prospect. Given the success of recent unmanned missions to Mars (e.g., Spirit, Opportunity, Curiosity), development of an in situ absolute dating instrument packages for future robotic missions is a logical next step. Although several ongoing programs of research are seeking to develop in situ packages for in situ application of the K-Ar technique with advanced mass spectrometry (e.g., Farley et al., 2013), these approaches could potentially deliver ages with questionable geologic meaning due to disturbed thermal histories and excess ^{40}Ar. The $^{40}Ar/^{39}Ar$ method utilizing neutron activation is the most promising geochronometer for obtaining accurate ages and thermal histories for rocks on the Martian surface but relies on the $^{39}K(n,p)^{39}Ar$ reaction so that ^{39}Ar can be measured as a proxy for the parent element K. This work explores the feasibility of developing a passive neutron source for space flight and in situ implementation of the $^{40}Ar/^{39}Ar$ method (e.g. Li et al., 2011).

Design Requirements



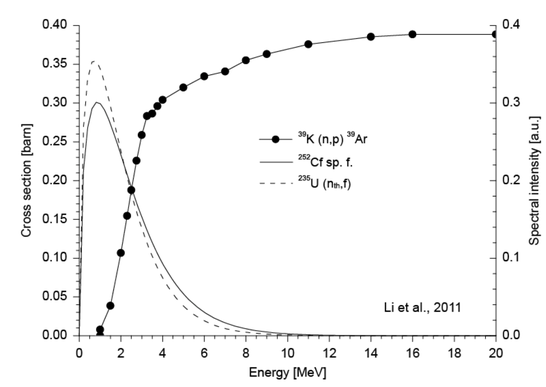
The primary limitation of this neutron generating device is that the mass must be sufficiently low that it will be no higher than ~45kg. This is more than half of the total instrument payload of Curiosity.



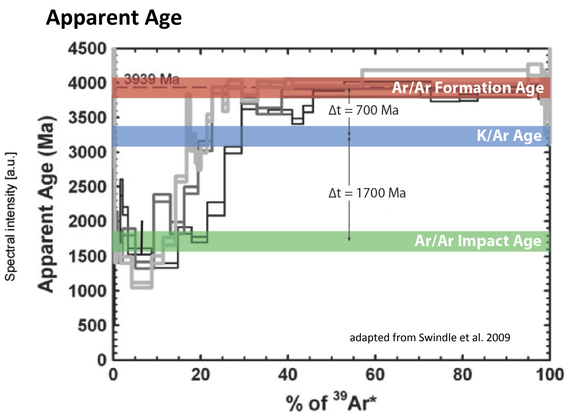
(Left) Illustrates required irradiation durations for various source flux values, based on OSU TRIGA flux. The following are assumed here:
(a) OSU "fast" flux = 2.5 x 10^{13} n/cm^2-s
(b) typical OSU irradiation, 4 Ga sample, requires 330 hours for $^{40}Ar/^{39}Ar$ = 100
(c) if we accept loss of precision, require 33 hours for $^{40}Ar/^{39}Ar$ = 1000
(d) somewhat arbitrary max. irradiation of 200 days.

A neutron source optimized for this type of neutron activation must provide a stable supply of fast neutrons over sufficient timescales, while also shielded with enough material such that the electronics of the rover do not accumulate an unsatisfactory level of neutron damage such that they may be rendered unusable.

^{252}Cf neutron energy spectrum



Apparent Age

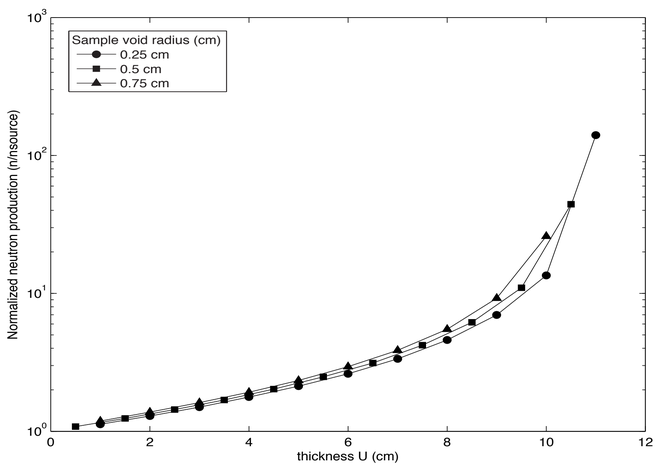


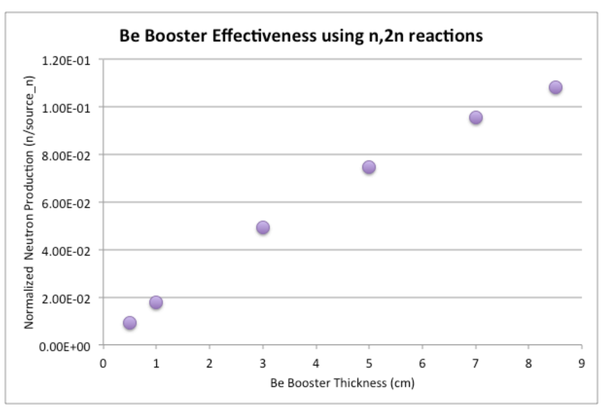
(Above, left) Neutron energy spectrum for ^{252}Cf relative to 235U, shown relative to the neutron capture cross section for the $^{39}K(n,p)^{39}Ar$ reaction. From Li et al. (2011).
(Above, right) Comparison of calculated age for a sample with impact history (as would be expected on the Martian surface)

Source Selection

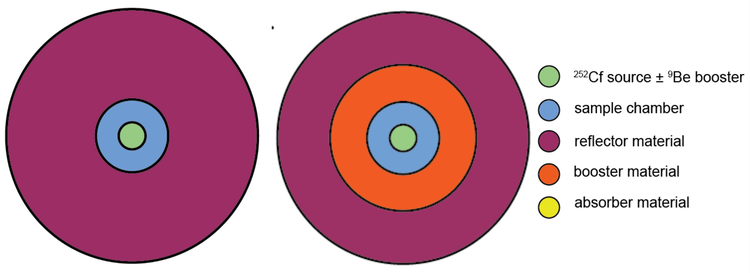
The neutron source has several constraints: (1) it must create fast neutrons with a relatively low thermal neutron flux, (2) it must have a sufficiently long half-life (on the order of years), (3), it must be quite a low mass, and, if possible, (4) it can be ramped.

Source	Mass required for 10^{11} n/s	n/s/mg	$t_{1/2}$	SF branching ratio (%)	Heat Output (Watts/10^{11}n/s source)
^{252}Cf	43 mg	2.3x10^{9}	2.645 years	3.82	1.43
^{250}Cf	9.5 g	1.1 x10^{10}	13.08 years	0.08	31
^{248}Cm	2.14 kg	4.7 x10^{10}	3.5x10^{5} years	8.26	1.04
^{246}Cm	9.8 kg	1.0 x10^{10}	4.7x10^{3} years	0.03	90
^{244}Cm	9.8 kg	1.0 x10^{10}	18 years	1.3x10^{-4}	2.4x10^{4}
^{253}Es	274 g	3.6 x10^{8}	20 days	8.7x10^{-6}	2.1x10^{5}
^{254}Fm	0.2 mg	5.0 x10^{11}	3.24 hours	0.06	33



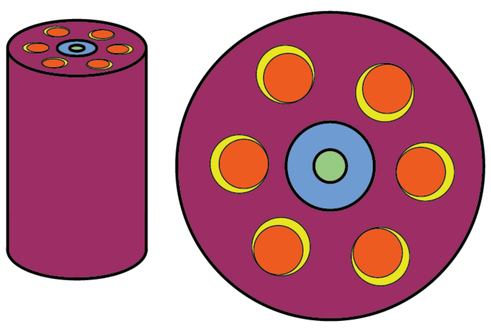


Device Configuration



Several device configurations were considered in this study. The first iteration included a point source of ^{252}Cf surrounded by a shield (above). Another iteration on this design considered boosting the ^{252}Cf with some other material, with n,2n reactions, like beryllium.

To avoid the considerable loss of neutrons over time, a subcritical assembly was also considered in this analysis. Two designs were proposed in this vein: one with removable pins of uranium, and the other with rotating drums of uranium with a highly absorbing material liner on half of the drum (below).



The results of this project are still ongoing, but the most attractive designs are those with a single source of ^{252}Cf.

Shielding Selection

The neutron shielding must be optimized with a short mean free path for scattering and thermalization and also with a very high absorption cross section for these thermalized neutrons. We performed parametric studies for shield optimization, of various compositions. It is evident that some composite shield structure will be the most optimal configuration for thermalization and absorption.