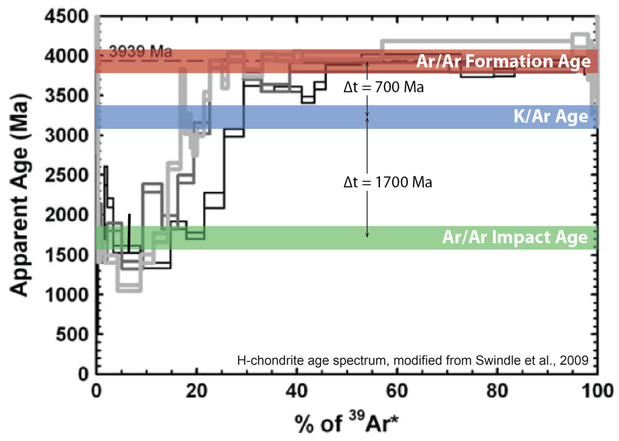
Instrumentation Development for Planetary in situ $^{40}Ar/^{39}Ar$ Geochronology

Leah E. Morgan[1], Brett Davidheiser-Kroll[1], Madicken Munk[2], Karl van Bibber[2], Patrick Harkness[3], Martin Lee[4], Ian Wright[5], Sanjeev Gupta[6], Darren Mark[1]

[1]Scottish Universities Environmental Research Centre, East Kilbride, G75 0QF, UK, [2]Department of Nuclear Engineering, UC Berkeley, [3]School of Engineering, University of Glasgow, [4]School of Geographical and Earth Sciences, University of Glasgow, [5]Department of Physical Sciences, Open University, [6]Department of Earth Science & Engineering, Imperial College London, UK

1. Planetary Geochronology

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 (e.g., Farley et al., 2013), these approaches could potentially deliver ages with questionable geologic meaning due to disurbed thermal histories (see Figure) and excess ^{40}Ar. The $^{40}Ar/^{39}Ar$ method 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 possibility 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).



2. Neutron source modelling (MCNP)

Neutron flux requirements (10^{10} - 10^{11} n/cm²/s)

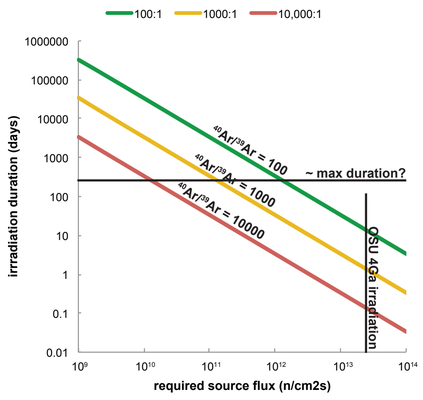


Figure 1. Shows required irradiation durations for various source flux values. Based on OSU TRIGA neutron flux, which approximates ^{252}Cf flux. The following are assumed here:

(a) OSU "fast" flux = 2.5 x 10^{13} n/cm²s

(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

Neutron source selection

Source	Mass Required for 10^11 n/sec	Half-life	SF Branching Ratio	Heat Output (Watts)
^{252}Cf	~43 mg	2.645 years	3.82%	1.43
^{250}Cf	9.5g	13.08 years	.08%	31
^{248}Cm	2.14kg	3.5E5 years	8.26%	1.04
^{246}Cm	9.80kg	4.7E3 years	.03%	90
^{244}Cm	9.82kg	18 years	.00013%	2.4e4
^{253}Es	274g	20 days	8.7e-06%	2.1e5
^{254}Fm	.2mg	3.24 hours	.06%	33

Figure 2. Passive neutron source options for space-flight. Note that many require large quantities (and masses) of material, and others have very short half-lives and/or large heat outputs. ^{252}Cf does have a short half-life but in general is the best option.

Be booster

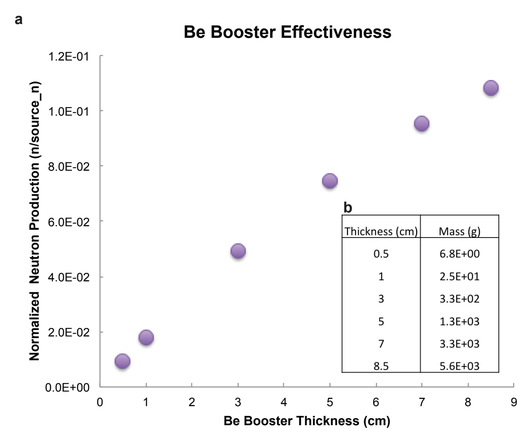


Figure 3. (a) Effectiveness of the addition of ^{9}Be to neutron source, which induces (n,2n) reactions. Unfortunately a large mass (6 kg) of Be is required to boost the source by even 10%. **(b)** Mass of Be for each thickness shown above.

Point source with spherical geometry

Cylindrical source with fissionable booster and cylindrical geometry

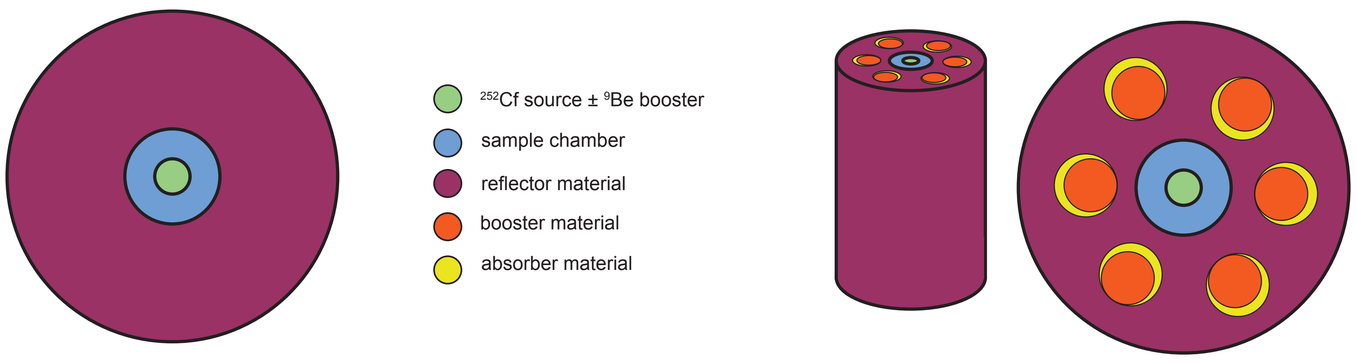


Figure 4. Possible source geometries. (a) Point source with Cf source surrounded by spherical sample chamber and shielding. MCNP modeling presented here is based on this design. (b) Cylindrical source surrounded by sample chamber and shielding, and rotatable (or removable) rods allow for variable amounts of fissionable booster material (e.g. ^{235}U) to exposed to the source.

3. Shielding

Shield mass limitations, MSL specs

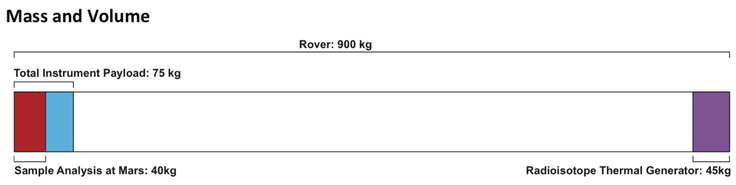


Figure 5. Mass specifications for the MSL mission. Total mass for neutron source needs to be reasonable considering total mass of SAM and MSL instrument payload. The possibility that the source could provide power to the rover may allow for higher mass and volume.

Shield effectiveness, polyethylene

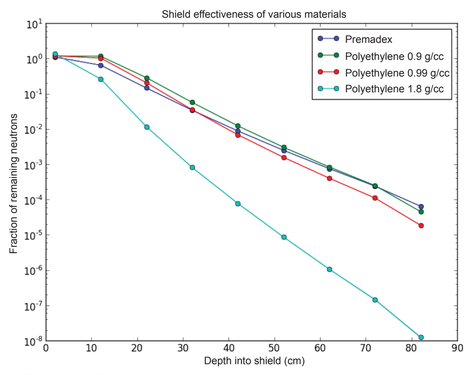


Figure 6. Shield effectiveness for polyethylene of various densities.

Shield effectiveness, other materials

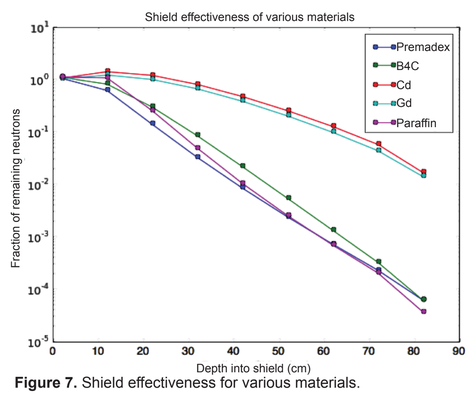


Figure 7. Shield effectiveness for various materials.

Shield effectiveness, composite shields

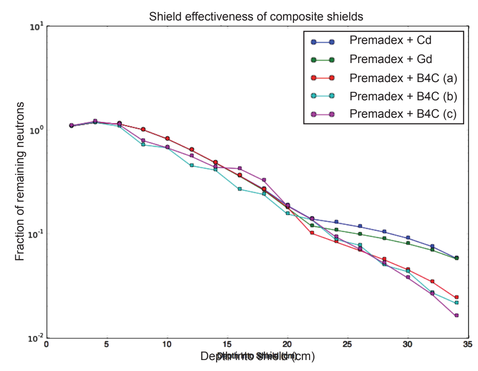


Figure 8. Shield effectiveness for composite shields. Premadex + Cd, Gd, and B4C (a) have 20 cm of Premadex surrounded by 14 cm of other material. (b) alternates B4C with Premadex every 2 cm in the shield. (c) has two B4C layers: one 8 cm and one 6 cm thick.