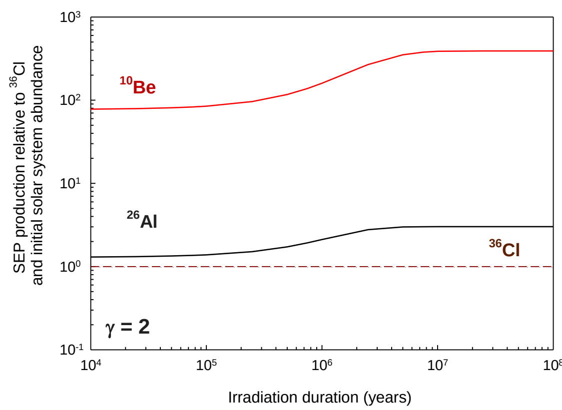
**PRODUCTION OF SHORT LIVED RADIONUCLIDES : LATE-STAGE IRRADIATION IN THE EARLY SOLAR SYSTEM.** K. K. Marhas and J.S. Randhawa, Physical Research Laboratory, Navrangpura, Ahmedabad, Gujarat, India 380009. kkmarhas@prl.res.in

The origin of now extinct radionuclides ($^{10}$Be, $^{41}$Ca, $^{26}$Al, $^{36}$Cl) in the early solar system provide stringent constraint on the formation of the solar system in terms of either stellar nucleosynthetic environment that encompassed our parent molecular cloud or high energetic environment within our solar nebula. Coupled presence of $^{41}$Ca and $^{26}$Al in Calcium Aluminum rich Inclusions (CAIs) vouch for stellar contribution as dominating source for the presence of short lived nuclides in the early solar system whereas presence of $^{10}$Be indicates solar energetic particle (SEP) interaction within the solar nebula as an alternate source for production of short lived nuclides. Further, decoupled existence of $^{10}$Be and $^{26}$Al in platelet hibonites indicated separate origin for these two short-lived nuclides and also assisted in estimating flux of SEP required to produce canonical $^{10}$Be observed in meteorites within the solar nebula. Production of $^{36}$Cl by SEP irradiation is usually coupled with the production of other short lived radionuclides.

Confirmed presence of now-extinct short lived radionuclide $^{36}$Cl ($t_{1/2}$ = 0.3 Myr) in secondary phases of refractory objects have been reported with an initial value $^{36}$Cl/$^{35}$Cl of around 5 x $10^{-6}$ [1-3]. Very recently, a high initial value ($^{36}$Cl/$^{35}$Cl ~ 2x $10^{-5}$) has been inferred from a wadalite sample from Allende CAI [4]. Decoupled presence of $^{36}$Cl and $^{26}$Al in this CAI is a definite indicator of a different source for these two short-lived nuclides. Relative time difference between the formation of two phases incorporating $^{26}$Al and $^{36}$Cl estimated from the initial value of $^{26}$Al/$^{27}$Al and $^{36}$Cl/$^{35}$Cl points towards the late irradiation scenario [4].

Due to high inital $^{36}$Cl/$^{35}$Cl value (~ $2\times10^{-5}$) obtained from wadalite in Allende CAI , Jacobsen et al. [4] inferred that formation of $^{36}$Cl must have occurred adjacent to the region in which the CVchondrite parent asteroid accreted and proposed that $^{36}$Cl was largely produced by late-stage SEP irradiation. It also indicates SEP irradiation must have occurred >2 Myrs after the formation of the first solar system solids.

Various irradiation models have been discussed for the production of short-lived nuclides present in the early Solar System. Differences in these models are mainly related to : (a) Astrophysical setting for irradiation (distances of the target material from the Sun: 0.06AU vs. 2-3 AU), (b) Physical nature of the target material (gas and dust), (c) Composition of the interacting gas and dust (CI, CAI ), and (d) Source of the cosmic ray. The major difference in the models discussed is the location/ region where the production of short lived radionuclides is assumed to take place, while Gounelle et al., and Leya et al. [5,6] assume an astronomical setting of X point region of the X wind model located at ~0.06 AU, the model of Goswami et al. [7] consider irradiation at 2-3 AU distance away from the Sun (asteroidal region).



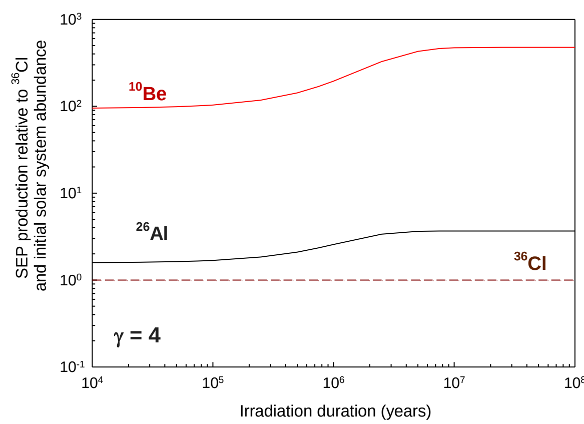




*Fig.1. Ratio of calculated to measured solar system initial ratios of $^{36}$Cl, $^{10}$Be relative to their reference isotopes, by SEP interactions plotted as a function of irradiation duration. With the constraint on observed $^{26}$Al/$^{27}$Al found in wadalite. The irradiated objects were assumed to be of sodalite composition following a power-law distribution in size (dn/dr α $r^{-4}$) with the spectral exponent of the SEP, γ =2 and 4. The SEP fluence was adjusted to produce an initial $^{36}$Cl/$^{35}$Cl ratio of 2x$10^{-5}$ for all irradiation duration.*

Using the model calculation used by Goswami et al. [7], production of $^{36}Cl$, $^{10}Be$ and $^{26}Al$ in the early solar system, due to SEP interaction with nebular material of Sodalite composition at asteroidal distances has been recalculated with the constraint on $^{26}Al/^{27}Al$ value of ~ 6 x $10^{-6}$ (as observed in the wadalite sample). The SEP flux is adjusted to match the observed initial $^{36}Cl/^{35}Cl$ ratio in wadalite (~$2\times10^{-5}$) [4] , for all the irradiation durations. Be concentration of 100 ppm in sodalite has been considered. Fig.1 indicates the irradiation product relative to $^{36}Cl$ and initial solar system for spectral exponent ($\gamma$) = 2 and 4 with the SEP power law [$dN/dE = kE^{-\gamma}$]

A flatter spectra ($\gamma$ = 2) for SEP interacting with a sodalite composition target seems consistent with the production of $^{26}Al$ as seen in grossular along with $^{36}Cl$ for shorter irradiation time scales. $^{10}Be$ is over produced for any irradiation timescale due to high abundance of $^{16}O$, the main target for SEP production of $^{10}Be$.

**References:** [1] Lin et al. (2005) *PNAS* 102: 1306. [2] Hsu et al. (2006) *Astrophysical Journal* 640: 525. [3] Ushikubo et al. *Meteoritics and Planet. Sci*, 42, 1267. [4] Jacobsen et al. (2011) *Astrophysical Journal* 731: L28. [5] leya et al. (2003) *Astrophysical Journal* 594: 605. [6] Gounelle et al. (2006) *Astrophysical Journal* 640: 1163. [7] Goswami et al. (2001) *Astrophysical Journal* 549: 1159.