

PRODUCTION OF He,Ne,Ar, and U-236 IN LUNAR MATERIAL BY SOLAR COSMIC RAY PROTONS, by J.R. Walton(a), D. Heymann(a), A. Yaniv(b), D. Edgerley(c), and M.W. Rowe(c); (a)-Department of Space Physics and Astronomy and Department of Geology, Rice University, Houston, Texas 77001;(b)-Department of Physics and Astronomy, Tel Aviv University, Ramat-Aviv, Israel; (c)-Department of Chemistry, Texas A&M University, College Station, Texas 77843.

In 12 irradiations at Texas A&M's Variable Energy Cyclotron, Mg,Al,Si, and CaF₂ foils were bombarded with 12-45 MeV protons. Cross sections for He-3,4, Ne-20,21,22 and Na-22 in Mg,Al, and Si and for Ar-36,37,38,39 in Ca were determined via mass spectrometry and gamma-ray counting. Combining these results with literature cross sections, excitation functions were constructed from threshold up to 45 MeV. By folding the excitation functions into differential SCR-proton spectra, production rates have been calculated for 2 π isotropic bombardment of a plane regolith at 50 different depths down to 25 g/cm². Saturation U-236/U-238 ratios from the reaction U-238(p,x)U-236 have also been calculated, using the excitation function from(1). Also, production rates for H³ in lunar material have been computed, in which case the excitation curve of "Al+p \rightarrow He³+X" was adopted. Tables 1 and 2 contain the results for integration up to 45 MeV for a SCR-proton spectrum representing the average flux of 3 high years(1956,1959,1960)(2). This spectrum in units of proton/cm²/yr. is: F(E>5MeV)=3.5E+10, F(>10)=2.0E+10, F(>20)=1.0E+10, F(>30)=6.0E+09, F(>40)=3.8E+09, F(>50)=2.5E+09, F(>100)=5.4E+08, F(>150)=1.1E+08, and F(>200)=3.6E+07. To produce U-236/U-238=233xE-09 found in 12070(1), a 20-fold more intense proton flux than the above is needed, if the U-236 was produced at the very top of the regolith(see Table 2). We are in the process of extending our excitation functions and integrations up to 200 MeV.

Footnotes for text and Tables: "E+10"=10⁺¹⁰, "E-08"=10⁻⁸, "E+00"=1, etc.

He-3d=Directly-produced He-3. He-3t=Sum of the directly-produced He-3 and that from complete decay of tritium. He4/3=He-4/He-3t production ratio. For lunar material, He-3 production was computed by averaging the individual production rates from Mg,Al, and Si(each 1.0 mass%) at each depth and multiplying this result by 100. The same procedure was adopted for He-4 production. For tritium production in lunar material we multiplied tritium production rates from Al(1.0 mass%) by 100. Ne22d=Directly produced Ne-22. Ne22t=Sum of the directly-produced Ne-22 and that from complete decay of Na-22. 20/22=Ne-20/Ne22t;21/22=Ne-21/Ne22t production ratios; 36/38=Ar-36/Ar-38 production ratio,etc. Ne production rates from Mg,Al, and Si and Ar production rates from Ca are for Mg=Al=Si=Ca=1.0 mass%. For 67701, we adopted the composition of 67461: Mg = 2.38, Al=16.0, Si=21.1, Ca=12.1 mass% (3). For 74220 we adopted: Mg=9.1, Al=3.4, Si=18.5, Ca=6.6 mass% (4). Ar-36 does not include production via Cl-36.

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SCR PRODUCTION OF He, Ne, Ar, AND U-236.

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Depth g/cm ²	Production Rates(cc STP/g-my) and Isotopic Ratios of Helium and Neon Produced by SCR Protons												From Silicon			
	For 1unar material				From Magnesium				From Aluminum				Ne22d		Ne22t	
	He-3d xE-08	He-3t xE-08	He4/3 xE+01	Ne22d xE-10	Ne22d xE+00	Ne4/3 xE-09	Ne22t xE+00	21/22 xE+00	Ne22d xE-10	Ne22t xE+00	21/22 xE-02	Ne22d xE-11	Ne22t xE+01	21/22 xE+00		
0.00	1.68 2.59	4.72 4.72	4.38 1.97	1.97 3.74	1.97 1.33	1.97 4.11	1.97 2.68	1.97 7.70	1.97 2.22	1.97 1.08	1.97 1.81	1.97 1.81	1.97 1.81	1.97 1.81	1.97 1.81	
0.05	1.38	2.13	4.09	3.59	1.40	3.87	1.19	1.52	3.56	2.23	7.79	1.94	0.925	1.83	4.41	
0.10	1.22	1.88	3.81	3.16	1.16	3.85	1.11	1.37	3.23	2.02	7.85	1.77	0.835	1.84	4.38	
0.15	1.10	1.69	3.63	2.85	1.01	3.81	1.05	1.26	2.97	1.88	7.89	1.63	0.765	1.85	4.36	
0.20	1.01	1.54	3.51	2.60	0.907	3.75	0.999	1.17	2.76	1.78	7.93	1.52	0.708	1.85	4.34	
0.25	0.928	1.42	3.42	2.39	0.824	3.69	0.961	1.09	2.57	1.70	7.97	1.42	0.659	1.86	4.33	
0.30	0.861	1.32	3.35	2.21	0.756	3.64	0.930	1.02	2.41	1.63	8.00	1.33	0.616	1.86	4.31	
0.35	0.802	1.23	3.29	2.07	0.699	3.59	0.904	0.961	2.27	1.58	8.02	1.26	0.579	1.87	4.30	
0.40	0.751	1.15	3.24	1.93	0.651	3.55	0.882	0.907	2.14	1.53	8.05	1.19	0.546	1.87	4.29	
0.45	0.706	1.08	3.21	1.82	0.609	3.51	0.863	0.858	2.03	1.50	8.07	1.13	0.516	1.87	4.28	
0.50	0.665	1.02	3.17	1.71	0.571	3.47	0.847	0.814	1.92	1.46	8.09	1.07	0.489	1.88	4.26	
0.55	0.628	0.959	3.14	1.62	0.538	3.44	0.833	0.773	1.83	1.43	8.11	1.02	0.464	1.88	4.25	
0.60	0.595	0.907	3.12	1.53	0.509	3.41	0.820	0.736	1.74	1.41	8.13	0.973	0.442	1.88	4.25	
0.65	0.565	0.861	3.10	1.46	0.482	3.38	0.809	0.702	1.66	1.38	8.15	0.930	0.421	1.88	4.24	
0.70	0.537	0.818	3.07	1.39	0.457	3.36	0.799	0.670	1.58	1.36	8.16	0.889	0.402	1.88	4.23	
0.75	0.511	0.779	3.06	1.32	0.435	3.33	0.791	0.641	1.52	1.34	8.18	0.852	0.384	1.88	4.22	
0.80	0.488	0.743	3.04	1.26	0.414	3.31	0.782	0.614	1.45	1.32	8.19	0.816	0.368	1.89	4.21	
0.85	0.466	0.710	3.03	1.20	0.395	3.29	0.775	0.588	1.39	1.31	8.21	0.784	0.352	1.89	4.21	
0.90	0.445	0.679	3.01	1.15	0.378	3.27	0.768	0.564	1.34	1.29	8.22	0.753	0.338	1.89	4.20	
0.95	0.426	0.650	3.00	1.10	0.361	3.25	0.762	0.542	1.28	1.28	8.23	0.724	0.324	1.89	4.19	
1.00	0.409	0.622	2.99	1.06	0.346	3.23	0.757	0.521	1.23	1.27	8.24	0.697	0.312	1.89	4.19	
1.50	0.280	0.426	2.91	0.727	0.237	3.11	0.717	0.365	0.865	1.18	8.34	0.493	0.218	1.90	4.13	
2.00	0.204	0.310	2.86	0.529	0.172	3.03	0.694	0.269	0.638	1.12	8.41	0.366	0.161	1.90	4.10	
2.50	0.154	0.234	2.83	0.401	0.130	2.97	0.679	0.205	0.487	1.09	8.46	0.281	0.123	1.90	4.07	
3.00	0.120	0.182	2.80	0.312	0.101	2.93	0.667	0.161	0.381	1.06	8.51	0.221	0.096	1.91	4.05	
3.50	0.095	0.144	2.78	0.247	0.080	2.89	0.658	0.128	0.305	1.04	8.54	0.177	0.077	1.91	4.03	
4.00	0.076	0.116	2.77	0.200	0.064	2.86	0.651	0.104	0.247	1.02	8.57	0.144	0.062	1.91	4.01	
4.50	0.063	0.095	2.76	0.164	0.053	2.84	0.645	0.085	0.203	1.00	8.60	0.118	0.051	1.91	4.00	
5.00	0.052	0.079	2.75	0.136	0.044	2.82	0.640	0.071	0.169	0.991	8.62	0.099	0.042	1.91	3.99	
5.50	0.043	0.066	2.73	0.114	0.037	2.80	0.635	0.060	0.142	0.980	8.64	0.083	0.036	1.91	3.97	
6.00	0.037	0.056	2.73	0.096	0.031	2.78	0.631	0.051	0.120	0.970	8.66	0.070	0.030	1.91	3.96	
6.50	0.031	0.047	2.72	0.082	0.026	2.77	0.628	0.043	0.103	0.961	8.68	0.060	0.026	1.91	3.96	
7.00	0.027	0.040	2.71	0.070	0.023	2.75	0.624	0.037	0.088	0.953	8.70	0.052	0.022	1.91	3.95	

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Depth g/cm ²	Production Rates(cc STP/g-my) and Isotopic Ratios Produced by SCR Protons: for Ar from Ca, for Ne and Ar in 67701 and 74220, and for U-236/U-238 Saturation Ratios in Lunar Material											
	From Calcium			For lunar soil 67701			Ar-38			For lunar soil 74220		
	Ar-38 xE-09	36/38 xE+00	37/38 xE-01	39/38 xE-03	Ne22t xE-08	20/22 xE+00	21/22 xE-01	Ar-38 xE-08	Ne22t xE-08	20/22 xE+00	21/22 xE-01	Ar-38 xE-08
0.00	2.32	1.41	3.88	4.62	1.15	3.41	6.75	2.81	1.96	3.81	1.27	1.53
0.05	1.98	1.23	2.87	4.51	0.922	3.16	5.71	2.39	1.41	3.91	1.14	1.30
0.10	1.77	1.15	2.48	4.48	0.812	3.00	5.23	2.14	1.18	3.87	1.06	1.17
0.15	1.61	1.09	2.25	4.46	0.733	2.88	4.92	1.95	1.04	3.82	0.998	1.07
0.20	1.49	1.04	2.09	4.46	0.672	2.78	4.70	1.80	0.932	3.76	0.954	0.982
0.25	1.38	1.01	1.98	4.46	0.622	2.71	4.53	1.67	0.849	3.70	0.919	0.911
0.30	1.29	0.982	1.89	4.46	0.579	2.64	4.39	1.56	0.781	3.65	0.890	0.849
0.35	1.21	0.959	1.83	4.46	0.542	2.58	4.28	1.46	0.724	3.60	0.866	0.796
0.40	1.13	0.939	1.77	4.46	0.509	2.54	4.19	1.37	0.675	3.56	0.846	0.748
0.45	1.07	0.922	1.73	4.46	0.480	2.49	4.12	1.29	0.632	3.52	0.829	0.706
0.50	1.01	0.908	1.69	4.47	0.454	2.46	4.05	1.22	0.594	3.49	0.815	0.667
0.55	0.958	0.895	1.66	4.47	0.430	2.42	4.00	1.16	0.561	3.45	0.802	0.632
0.60	0.910	0.883	1.63	4.48	0.409	2.40	3.95	1.10	0.530	3.42	0.791	0.601
0.65	0.866	0.873	1.61	4.48	0.389	2.37	3.91	1.05	0.502	3.40	0.781	0.571
0.70	0.825	0.864	1.59	4.49	0.371	2.35	3.87	0.998	0.477	3.37	0.772	0.554
0.75	0.787	0.855	1.57	4.49	0.354	2.32	3.84	0.952	0.454	3.35	0.764	0.519
0.80	0.752	0.848	1.56	4.49	0.339	2.30	3.80	0.910	0.433	3.33	0.756	0.496
0.85	0.720	0.841	1.54	4.50	0.324	2.29	3.78	0.871	0.414	3.31	0.750	0.475
0.90	0.689	0.834	1.53	4.50	0.311	2.27	3.75	0.834	0.395	3.29	0.744	0.455
0.95	0.661	0.828	1.52	4.51	0.298	2.25	3.73	0.800	0.378	3.27	0.738	0.436
1.00	0.635	0.823	1.51	4.51	0.286	2.24	3.71	0.768	0.363	3.26	0.733	0.419
1.10	0.440	0.783	1.44	4.54	0.199	2.13	3.56	0.532	0.249	3.14	0.698	0.290
2.00	0.322	0.759	1.41	4.57	0.146	2.07	3.47	0.389	0.181	3.06	0.677	0.212
2.50	0.244	0.743	1.39	4.58	0.111	2.03	3.42	0.295	0.137	3.01	0.663	0.161
3.00	0.190	0.730	1.37	4.60	0.087	1.99	3.38	0.230	0.106	2.97	0.653	0.125
3.50	0.151	0.721	1.36	4.61	0.069	1.97	3.34	0.183	0.085	2.94	0.644	0.100
4.00	0.122	0.713	1.35	4.63	0.056	1.93	3.32	0.148	0.068	2.91	0.638	0.081
4.50	0.100	0.706	1.35	4.64	0.046	1.91	3.30	0.121	0.058	2.89	0.632	0.066
5.00	0.083	0.700	1.34	4.64	0.038	1.90	3.28	0.101	0.046	2.87	0.628	0.055
5.50	0.070	0.695	1.34	4.65	0.032	1.88	3.26	0.084	0.039	2.85	0.624	0.046
6.00	0.059	0.690	1.33	4.65	0.027	1.87	3.24	0.071	0.033	2.84	0.620	0.039
6.50	0.050	0.686	1.33	4.67	0.023	1.86	3.23	0.061	0.028	2.82	0.617	0.033
7.00	0.043	0.683	1.33	4.67	0.020	1.86	3.22	0.052	0.024	2.81	0.614	0.028