EVIDENCE FOR A LARGE, NATURAL, PALEO-NUCLEAR REACTOR ON MARS. J. E. Brandenburg, Orbital Technologies Corporation, Space Center, 1212 Fourier Drive, Madison WI 53717 brandenburgj@orbitec.com

Introduction: On Earth, in the regions of Oklo in Africa, 1 billion years ago, natural uranium ore and groundwater interacted to form natural nuclear reactors at 5 locations. [1] These reactors were small and self-regulating , groundwater infiltrating the ore deposit would moderate neutrons leading to criticality, leading in turn, to nuclear heat production and groundwater expulsion with subsequent loss of criticality. These natural nuclear reactors cycled for several million years, breeding plutonium , before shutting down. On Mars, the same ingredients of groundwater and uranium are present and it is likely that similar natural nuclear reactors formed and operated in Mars distant past. Evidence exists that a large natural nuclear reactor formed and operated on Mars in the northern Mare Acidalium region of Mars. However, unlike its terrestrial analogs this natural nuclear reactor was apparently much larger, bred ^{233}U off of thorium, and apparently underwent explosive disassembly, ejecting large amounts of radioactive material over Mars surface [2]. Evidence of a large scale nuclear activity on Mars comes from a variety of sources. It has been a long standing paradox that uranium, thorium and potassium, appear hyper-abundant on Mars surface when compared to Mars meteorites, which are believed to sample subsurface rocks. [3] Thorium and radioactive potassium appear concentrated in the northern Mare Acidalium in the region of the large, shallow depression north of Acidalia Colles., with a small concentration at the approximate antipode of this region on the other side of the planet (see Figure 1and 2).

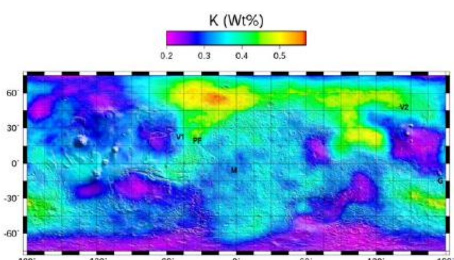

Figure 1. Distribution of radioactive K on Mars

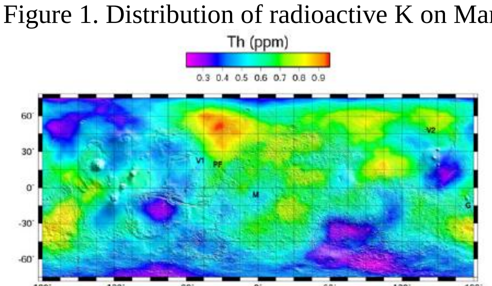

Figure 2. Distribution of Th on Mars

It is also known that xenon and argon components of Mars atmosphere are dominated by radiogenic isotopes when compared to terrestrial or averaged Carbonaceous Chondrite standards. In addition Mars meteorites give evidence of being irradiated by neutrons with total flux of 10^{15}/cm^2 while on Mars [4] based on their Kr 80 abundance, however, Eugster has recently argued for a cosmogenic origin of this irradiation [5].

In addition to this evidence of a nuclear event, we have circumstances on Mars that could actually be more conducive to natural nuclear reactors than conditions on Earth: a lack of plate tectonics, meaning retention of impacting bodies or concentrated ore bodies in the regolith is more likely, and nearness to the asteroid belt as a possible source of uranium and thorium rich bolides. Mars has experienced a greater loss of geothermal heat in recent geologic history, leading to a deepening in ground water distribution. Together this data can be used to form a hypothesis.

The Martian Large, Natural, Paleo-Nuclear Reactor Hypothesis: In Mare Acidalium, a large ore body of incompatible elements formed with concentrated uranium, thorium and potassium at kilometer depth, probably from an asteroidal impact. Due to the lack of plate tectonics, the ore body was not disrupted over Mars history but supported nuclear fission reactions based on a thermal mode. This process began 1 billion years ago when ^{235}U was three percent and may have been triggered by a deep intrusion of groundwater into the ore body due to loss of geothermal heat on Mars. The body was of high concentration of uranium and thorium oxides. After many millions of years in operation the paleo-reactor managed to begin breeding fuel in the form of ^{233}U and ^{239}Pu faster than it was burned up. Much radioactive potassium was also created by the neutron flux during this period of thermal neutron operation. At some point the ore body suffered a “prompt critical” and the water boiled out making the neutron spectrum harder and a runaway chain reaction on the ^{233}U and ^{239}Pu ensued. Because of the size of the ore body, and its burial at kilometer depth, the reaction was inertially confined or “tamped” so that explosive disassembly was delayed until a high degree of fission burn-up was achieved. The resulting energy release was catastrophic and resulted in an explosive disassembly of the ore body as a dust and ash cloud similar to a large asteroid impact. This resulted in dust and rock falls over large areas of the planet, and this layer was enriched in U and Th over the base rocks of the Mars surface. Delayed neutrons, of approximately 1% of the core neutron flux irradiated the planet's surface for several minutes as debris rained down to form a global layer. The explosion formed an approximately 400km wide, shallow depression at the center of the surface distribution of radioactive debris north of Acidalia Colles.

Fission Yield Calculations*:* Based on the observed abundances of Mars Xe and Kr isotopes and the observed enriched layer of U and Thorium on its surface over subsurface rocks, it is possible to estimate the number of fissions that occurred under this hypothesis and thus the energy release and approximate size of the original concentrated ore body. Based on the abundance of ^{129}Xe in the Mars atmosphere and assuming it was all produced in the explosion at approximately a fractional mass yield into the atomic mass 129 channel of F_{129}=3% for a fast neutron spectrum [6]. We can write for the total energy released based on ^{129}Xe:

$$W_{Xe} = W_{fission} n_{Xe129} AH / F_{129} \cong 1.5x10^{25} J \qquad (1)$$

where $W_{fission}$ is the energy released per fission of 200Mev or 3.2x 10^{-11}J, n_{Xe129} =9x10^{10} cm^{-3} is the number density of ^{129}Xe in the Mars atmosphere, A is the surface area of Mars of 1.4 x 10^{18}cm^2 and H =1.1 x 10^6 cm is the Martian atmosphere scale height. This is a large energy, equivalent to the impact of a 30km diameter asteroid into Mars and sufficient to produce a global ejecta layer of many meters [7].

Based on the $F_{neutron}$ = 10^{14}/cm^2 neutron fluence required to explain the irradiation of lithogies B, C of EETA79001 [4] and account for the ^{80}Kr anomaly, and assuming this was a planet-wide occurrence from delayed neutrons of an approximate fraction $F_{delayed}$ = 0.1% that were radiated immediately after the event by fission fragments in the planet-wide ejecta layer, we can calculate and approximate number of fissions in the event and thus have an independent estimate of the yield. We can estimate the yield from the ^{80}Kr anomaly:

$$W_{Kr} = W_{fission} F_{neutron} A / F_{delayed} \cong 4.6x10^{25} J \qquad (2)$$

where the values of other quantities $W_{fission}$ and A are the same as in Eq. 1.

Assuming a thickness L=1 meter layer of Th and U of concentration C = 0.5 ppm of a total molecular number density of n=6x10^{22} cm^3 covering the planet's surface and, similar to Oklo, that this is the remnants of a concentrated ore body where approximately a fraction $F_{fissionable}$= 3% of the ore body was fissionable and was consumed in the explosion, we can again estimate the total energy yield:

$$W_{U-Th} = W_{fission} F_{fissionable} CnAL \cong 4x10^{24} J \qquad (3)$$

The original ore body, if it was approximately pure (Oklo was 70%), would have been approximately the volume of 0.14 cubic kilometer and the explosion would have been a planetary scale catastrophe, creating a crater approximately 100's of kilometers wide and kilometers deep. However, unlike an asteroid impact, the center of the explosion would have been much closer to the surface and hence would have had much quicker pressure relief, resulting in a wider, shallower, crater than an asteroid impact of the same energy. The observed region of concentrated Th is located in Northwest Mare Acidalia in shallow wide depression centered at approximately 15W and 50 N. The appearance of a region of enhanced Th and radioactive K is not reflected in maps of shorter lived Fe and Si isotopes and indicates the event occurred several hundred million years ago and probably dates to the middle or late Amazonian epochs. Weak irradiation of lithogies in ETA79001 indicate 180 million year or older age for the disassembly event. Based on the predominance of ^{40}Ar, formed by thermal neutrons over ^{129}Xe formed by high energy neutrons, it can be estimated that the paleo-reactor operated for long periods, perhaps 100 million years, in a quiescent thermal mode before disassembly occurred. Given the ratio of ^{40}Ar to ^{129}Xe in the atmosphere, the ratio of thermal fissions to fast neutron fission during the explosive disassembly is approximately $\#Fiss._{Thermal} / \#Fiss._{Prompt} \cong 10^7$ .This is consistent with the requirement of breeding large amounts of ^{233}U and ^{239}Pu in a long period of thermal cycling to support a later prompt critical event.

Discussion: Natural Nuclear Reactors formed and operated on Earth, there is no reason this could not have happened on Mars. Conditions on Mars: lack of plate tectonics, and nearness to the asteroid belt, may have favored such occurrences in larger size and duration than on Earth. Changes in groundwater distribution, due to either climate change or loss of geothermal heat, may have triggered this event. The occurrence of such a large natural reactor may explain some puzzling aspects of Mars data, such as the superabundance of K and Th on the surface and the large inventory of radiogenic isotopes in Mars atmosphere.

References: [1] Meshik, A. P., Hohenberg C.M., and Pravdivtseva O. V. (2004) Phys. Rev. Lett., 93, 182302. [2] Brandenburg, J.E. Proceedings of Spring AGU Meeting 2006. [3] Taylor G.J. et al. (2003) Proc. 6th International Conference on Mars. [4] Swindle, T. D., Caffee, M. W., and Hohenberg, C. M., (1986) Geochimica et Cosmochimica Acta, 50, pp 1001-1015. [5] Eugster, O. et al. (2002) Meteor. Planet. Sci. 37, 1345.[6] Vandenbosch, R., et al. , (1973) Nuclear Fission, Academic Press Inc. NY NY p 307-315 [7] Sleep N. H., Zahle K. (1998) Jou. Geophys. Res. Vol 103, E12, 28529-28,544.