POSSIBLE ORIGIN OF LOW TEMPERATURE XENON COMPONENTS IN NANODIAMOND-RICH SEPARATES FROM PRIMITIVE METEORITES. A. Meshik and O. Pravdivtseva, Physics Department and McDonnell Center for Space Sciences, Washington Univ., St. Louis, MO63117, USA (ameshik@physics.wustl.edu)

Nanodiamond-rich residue (~0.15 wt.%) remaining after chemical dissolution of primitive meteorites contains four distinct xenon components: P3, Q, HL, and P6 sequentially releasing from the residue with increase of extraction temperature [1, 2]. The first two components, P3-Xe and Q-Xe, seem to be closer to mass-fractionated solar Xe than the HL-Xe and P6-Xe which are considered to be “exotic” [3]. Each of these Xe components has a specific isotopic composition which was determined at intersection of mixing lines formed by experimental points in 3-isotope plots during stepwise pyrolysis of the residue [1, 2]. The Xe components are not necessarily of a single origin, but a mixture of sub-components with isotopic structures corresponding to products of known physical processes. For example, HL-Xe is believed to be an ultimate mixture of products from p- and r- astrophysical processes, while Q-Xe is seemingly an isotopically fractionated solar Xe with variable addition of HL-Xe [4] and possibly s-process Xe [5]. P3-Xe releasing at the lowest temperature carries some addition of $^{129}\text{I}$ (15.7Ma). This $^{129}\text{I}$ turned out to be in “intricate relationship” with the rest of P3-Xe isotopes releasing from the nanodiamond-rich residue [6].

To account for complexity of Xe components in the nanodiamond residue it was assumed that each of them has been acquired by different subsets of carbonaceous particles during distinct astrophysical events [7]. Then these particles with different susceptibilities to thermal metamorphism were accreted into a parent body of a meteorite preserving the record of these events. In this approach, each Xe trapping site has different Xe retention and therefore the memories about different Xe incorporation events are not equally preserved [4]. Q-Xe is presently the most abundant Xe component in meteorites, but based on the P3-Xe and $^{129}\text{I}$ release from nanodiamond-rich residue separated from CI chondrites, it was suggested that P3-Xe was even more abundant when it was acquired by meteorites [8].

Therefore P3 is considered to be the most primitive Xe component contemporary to the formation of massive stars [4, 6, 7]. P3-Xe apparently exhibits s-process deficit. That required a revision of the original model [7]. The new model suggests that “processing in interstellar medium gradually creates P3 sites, that retain xenon originally trapped in Q-sites” [6].

Deciphering the origin of nearly isotopically “normal” Q-Xe and P3-Xe is evidently not a trivial task. One has to simultaneously “fine tune” the sequence of astrophysical events and mechanisms of Xe incorporation into specific sub-populations of carbonaceous material with very specific properties. In this work we attempted to look at Q-Xe and P3-Xe from different perspectives. In order to understand the differences between Q-Xe and P3-Xe we examined their similarities and identified a physical process capable of transforming the isotopic signature of Q-Xe into P3-Xe without involving galactic evolution of P3 and Q components.

Figure 1a shows the difference between P3-Xe and Q-Xe, with both being normalized to $^{138}\text{Xe}$. In this representation they are different only in four isotopes $^{129}\text{Xe}$, $^{132}\text{Xe}$, $^{131}\text{Xe}$ and $^{134}\text{Xe}$. All other isotopes are indistinguishable within uncertainties. Compared to Q, P3 is enriched in $^{129}\text{Xe}$, supposedly due to decay of extinct $^{129}\text{Xe}$ pointing to a more primitive nature of P3 relative to Q. That is why P3 was considered to be a common ancestor from which Q and solar Xe have been evolved [4, 6, 7], while the $^{131-134}\text{Xe}$ excess is likely the innate signature of P3, the nearly-disappeared (except for nanodiamond-rich separates) predecessor of all presently existing Xe components.

Interestingly, the P3 isotopic signature has been clearly observed in “fines” from Greenland anorthosite [9] (Fig. 1b). It is not only ×50 more pronounced than in P3, but also complimented with $^{129}\text{Xe}$ excess, seemingly unrelated to primordial $^{129}\text{I}$ decayed long before the anorthosite has been formed 2.9Ga ago. This unusual Xe structure has been considered to be an artifact [10] until it was reproduced experimentally (Fig. 1c) [11]. The low temperature extractions from the acid-treated U-bearing sample exhibits significant isotopic anomalies, which were not present in the original, untreated sample (Fig. 1c). Remarkable similarity of isotopic shifts (a) between P3 and Q, (b) between “fines” and coarse minerals in the anorthosite, and (c) between low temperature release of fission Xe and the whole U-bearing rock clearly suggests a common mechanism producing this effect, which was labeled CFF (Chemically Fractionated Fission). The CCF is caused by diffusion of “hot” atoms of radioactive Xe precursors, mainly I and Te. The longer the mobile radioiodine lives, the farther from the radiation damaged zones it can diffuse. This process does not manifest itself in a bulk sample where Xe isotopic micro-distribution caused by CFF is averaged. But when the bulk sample containing fission products is powdered, weathered, or...
treated with acids, a small fraction of the processed sample exhibits the CFF-modification of normal fission Xe yields. This occurs at low temperature corresponding to release of surface correlated gas which already lost complimentary isotopes: nearly all $^{136}$Xe, half of $^{134}$Xe, ~1/4 of $^{132}$Xe and ~1/8 of $^{131}$Xe [11]. This pattern observed in Xe-Q (Fig. 2a) is remarkably similar to Xe found in the gas bubbles released from acidic pools containing nuclear wastes [12] where the CFF process has been “caught in action”.

Fig. 1. Isotopic composition of P3-Xe (a) compared to Q-Xe is nearly identical to the composition found in fine-grain fraction of terrestrial anorthosite [9] (relative to the bulk [10]) (b). Similar isotopic structure is observed in acid-resistant residue from U-bearing sample [11] (c). In all cases this characteristic isotopic structure is observed only in fine-grained fractions at the lowest extraction temperatures and is not seen in the bulk samples degassing at major high temperature release. Chemically Fractionated Fission (CFF) [11] is the only known process which can produce the isotopic shifts observed in these diverse samples.

All Xe “anomalies” showed in Figures 1a, 1b, 1c have one thing in common: they are not detectable in bulk, chemically untreated samples. Only in acid residues, and only at very low temperature, the CFF-process becomes apparent. In some sense, P3-Xe is man-made. It has been created in the fume hood where the samples were treated.

Fig. 2. Xe-Q can be modelled as slightly fractionated solar Xe with ~3% addition of “steep” heavy Xe component (a). The identical Xe structure is observed in gas bubbles releasing from the acid sludge containing spent nuclear fuel [12] (b). This “Xe-H-like component is evidently not a part of Xe-HL. The steep heavy isotope enrichment is complimentary to depletion of these isotopes in samples shown in Figure 1. It is likely produced by CFF [11] modified $^{239}$Pu (and/or $^{238}$U) fission yields.

Our recent experiment [11] and the observations reported here suggest the following tentative relationship between solar Xe, Q-Xe and P3-Xe. Q-Xe is slightly (only 0.65%/u) fractionated solar Xe with ~3% (for $^{136}$Xe) addition of CFF-Xe from $^{239}$Pu (or/and $^{238}$U). Isotopically complimented CFF-Xe forms P3-Xe. $^{129}$Xe present in P3 may not be entirely from primordial $^{129}$I decay, but from the fission radioiodine. To quantify this we need to know the $^{239}$Pu fission yield for $^{129}$I.

If our interpretation is correct, there is little hope to access galactic evolution using the low-temperature Xe components (P3 and Q) in nanodiamond-rich residue. The origins of these Xe components are likely to be “local” rather than “presolar”.

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