NANODIAMONDS OF METEORITES: EXTREME ISOTOPIC COMPOSITION OF XENON COMPONENTS.

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Introduction: Up to now the analysis of the xenon component contents in nanodiamond in meteorites has been carried out within the framework of two variants of their isotopic compositions [1, 2]. In one of them (variant A) it is used the isotopic compositions of Xe-P3, Xe-P6 and Xe-HL xenon components [1], while in another variant (variant B) Xe-P3 and Xe-P6 components are also used, but instead of Xe-HL, the component designated by us as Xe-prHL [2] is used. The isotopic composition of this component is equal to the composition of the isotopically anomalous subcomponent in Xe-HL. The modeling of the measured isotopic compositions of Xe in diamond of various meteorites in the both variants showed the similar results. However, the contents of Xenon components obtained are sharply different. As can be seen, these different lead to different possible interpretations of Xe components origin.

In this work, we present the modeling results of measured of isotopic xenon composition with using of Xe-P3 and two new of Xe components (denoted as Xe-prHL and Xe-prP6ex). The results of the analysis on xenon released during the stepwise pyrolysis of nanodiamond from the Orgueil (CI) and Indarch (EH3-4) meteorites [3], which are sharply different in the degree of thermal metamorphism, are given.

Determination of xenon component contents in meteorite nanodiamonds: Calculations of the xenon component contents Xe-P3, Xe-prHL, Xe-prP6ex were carried out on the basis of the measured contents of xenon and its isotopic composition in nanodiamond of the Orgueil (CI) and Indarch (EH4) meteorites in [3]. Note that the Xe-prH and Xe-prP6 isotopic compositions were obtained under the assumption that the ^{130}Xe contents in the Xe-HL and Xe-P6ex components are due to the Xe-P3 component only. Therefore, Xe-prHL and Xe-prP6ex consist mainly of $^{124-126}$Xe and $^{134-136}$Xe, which are formed only in p- and r-processes, for example, at a type II supernova explosion. In the calculations, it was taken into account that the noble gases in the separated diamond-enriched fractions also contain Xe-S, the phase, carriers of which are the SiC nanograins. The calculations were carried out using the following equations:

$$X + Z + Y + V = [^{132}\text{Xe}]_m$$

$$(^{130}\text{Xe}/^{132}\text{Xe})_{P3} \times X + (^{130}\text{Xe}/^{132}\text{Xe})_S \times V = (^{130}\text{Xe}/^{132}\text{Xe})_m \times [^{132}\text{Xe}]_m$$

$$(^{134}\text{Xe}/^{132}\text{Xe})_{P3} \times X + (^{134}\text{Xe}/^{132}\text{Xe})_{prP6} \times Z + (^{134}\text{Xe}/^{132}\text{Xe})_{prHL} \times Y + (^{134}\text{Xe}/^{132}\text{Xe})_S \times V = (^{134}\text{Xe}/^{132}\text{Xe})_m \times [^{132}\text{Xe}]_m$$

$$(^{136}\text{Xe}/^{132}\text{Xe})_{P3} \times X + (^{136}\text{Xe}/^{132}\text{Xe})_{prP6} \times Z + (^{136}\text{Xe}/^{132}\text{Xe})_{prHL} \times Y + (^{136}\text{Xe}/^{132}\text{Xe})_S \times V = (^{136}\text{Xe}/^{132}\text{Xe})_m \times [^{132}\text{Xe}]_m,$$

where X, Z, Y, V variables are the contents of ^{132}Xe-P3, ^{132}Xe-prP6, ^{132}Xe-prHL and ^{132}Xe-S, respectively. The subscripts P3, prP6, S, and prHL relate to the isotopic compositions of xenon components (Table 1), while m corresponds to the ^{132}Xe content and xenon isotopic ratios, which we used on the basis of the measured in [3] at the pyrolysis of meteoritic nanodiamond.

All calculations were carried out by normalizing the equations to the measured ratios ^{130,134,136}Xe/^{132}Xe without taking into account the measurement errors. Therefore, the contents of Xe components in meteorite nanodiamonds obtained below represent one of the variants of their possible values.

Results and discussion: Based on the calculated contents of the components Xe-P3, Xe-prHL and Xe-prP6 with using the measured contents of ^{132}Xe and ratios $^{130, 134, 136}$Xe/^{132}Xe at the stepwise pyrolysis of Orgueil (CI) and Indarch (EH4) nanodiamonds, it was established the following.

1 The contents of all xenon isotopes in the Xe-P3, Xe-prHL and Xe-prP6 components and the Xe-S content are equal to (10^{-8} cm^3/g): 187.33, 8.82, 2.36, 0.10 and 114.78, 12.59, 8.058, 0.32, respectively. As you can see, the content of Xe-P3 significantly exceeds the content of other components even in the diamond of the thermally metamorphosed meteorite Indarch. Note that in this meteorite's diamond when Xe-HL is used, the Xe-P3 component is practically not observed..

2. The calculated isotopic ratios of ($^{124-128}$Xe/^{132}Xe and $^{131-136}$Xe/^{132}Xe) for the total xenon do not differ from the measured component ratios by more than 14 and 5 ‰ on Xe of the Indarch diamond, and by 6 and 1 ‰ on Xe of the Orgueil diamond (Fig. 1).
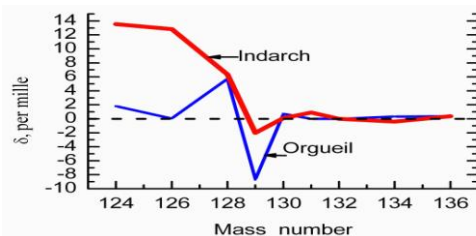

Figure 1.Deviation of the calculated Xe isotopic compositions from measured.

These calculations of the isotopic composition were carried out based on the calculated of the total contents of ^{132}Xe in each of the components Xe-P3, Xe-prHL, Xe-prP6, and also Xe-S. The excess of the calculated light isotopes over those measured on Xe of the Indarch diamond may be due to the loss of these isotopes during the thermal metamorphism of this meteorite. For Xe in the diamond of both meteorites, the calculated ^{129}Xe/^{132}Xe ratios are lower than the measured ones.

The underestimation of this ratio is probably due to the fact that we did not take into account the contribution of ^{129}Xe from the decay of its radioactive precursor ^{129}I. It is important to note that the deviations of the calculated xenon isotopic ratios during the stepwise pyrolysis of diamond in meteorites are basically similar to those when using a mixture of components with Xe-HL [3], as well as when using Xe-pr instead of Xe-HL [2]. This similarity testifies about the possible reality of each of these component mixtures equally.

3. The release of the main part of the Xe-P3 component during stepwise pyrolysis of nanodiamond of both me-

teorites is observed at T>1000°C, as well as xenon of other components (Fig. 2).
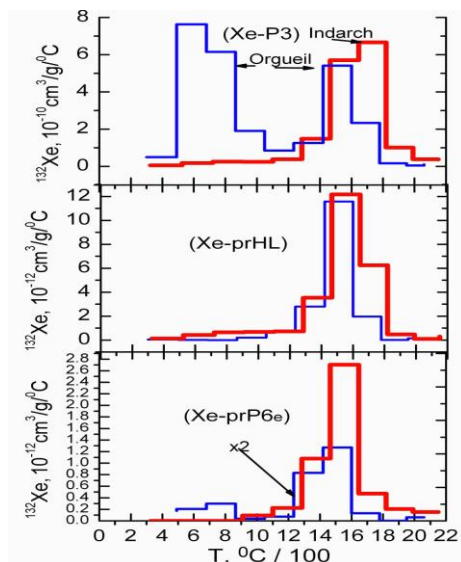

Figure 2. Xe components extraction histograms.

High-temperature maxima of component release are located in the series Xe-P3> Xe-prHL >> Xe-prP6ex. The sharp difference of these temperatures indicates on the presence of xenon components in individual populations of grains with different thermal stability.

4. The value of the $^{124}Xe/^{136}Xe$ ratio for the Xe-prHL component is higher than that for Xe-prP6ex by (2.7 ± 0.2)%, while for the $^{134}Xe/^{136}Xe$ ratio this excess is (14.4 ± 0.3)%. The observed differences may be due to the different half-lives of the radioactive precursors ^{124}Xe, ^{134}Xe, and ^{136}Xe. Therefore, on the basis of Ott's model, Xe-prHL and Xe-prP6ex components are the result of the capture of Xe, formed during different periods of decay of its radioactive precursors since the supernova explosion. In addition, we assume the presence of a spatial gradient in thermal stability in the distribution of diamond grains relative to the supernova.

Calculations of the time intervals for the formation of the Xe-prP6ex and Xe-prHL components showed that they are equal to 1.89 h and 2.17 h, respectively., and the grain population of the first component is more heat-resistant than the second. At the same time, the obtained duration of the trapped time for Xe-prHL does not correspond, in particular, to the high value of the $^{132}Xe/^{136}Xe$ ratio in this component. The question about the origin of excess ^{132}Xe remains open and further research is needed to solve it. However, the assumption of the formation of Xe-prHL and Xe-prP6ex according to Ott's model [4] after explosion of a type II supernova is currently the most probable. Отметим, что наиболее вероятно the source of the population of Xe-P3 grains is the interstellar medium. Note that the source of the population of Xe-P3 grains is the interstellar medium most likely.

Conclusion: The data obtained here show that the modeling of measured Xe isotopic compositions in nanodiamonds of meteorites can be carried out using Xe-prHL, Xe-prP6ex and Xe-P3 components in diamonds. This Xe component composition differs significantly from the compositions in [1, 2], which were also successfully used for modeling. However, it is not possible to determine which of the used alternative compositions of Xe can be real without additional selection criterion. This criterion may be the assumption that the relative content of the population of diamond grains with anomalous Xe is extremely minimal [6]. In this case, the Xe composition with extreme components is the most similar to the real Xe composition.

References: [1].Huss G.R and Lewis R.S. (1994) *Meteoritics &Planet. Sci.*, 29, 811–829. [2] Fisenko A.V. and Semjonova L.F. (2020) *Solar System Research*, 54, 3, 253-262.[3].Huss G.R. and Lewis R.S. (1994) *Meteoritics & Planet. Sci.*, 29,. 791–810.[4] Lewis R.S. et al. (1994) *Geochim. Cosmochim. Acta.*, 58, 471–494. [5] Ott U. (1996) *Astrophys. J.,* 463, 344–348. [6]. Lewis J.B. et al. (2019)) *Meteoritics & Planet. Sci.*, 1–22.

Table 1 Isotopic composition of xenon components ($^{132}Xe = 100$)

Component	^{124}Xe	^{126}Xe	^{128}Xe	^{129}Xe	^{130}Xe	^{131}Xe	^{134}Xe	^{136}Xe
Xe-HL[1]	0.842(9)	0.569(9)	9.05(6)	105.6(2)	15.44(3)	84.42(13)	63.61(13)	70
Xe-P3[1]	0.451(6)	0.404(4)	5.06(2)	104.2(4)	15.91(2)	82.32(10)	37.70(10)	31.0
Xe-S[2]	0	0.033(19)	21.59(14)	11.8(1.1)	48.26(42)	18.6(1.2)	2.22(53)	0.34
Xe-P6e[1]	0.687(8)	0.521(8)	8.99(5)	107.8(2)	15.89(3)[3]	83.55(13)	51.80(13)	55
Xe-prHL	13.68	5.99	41.57	151.6	0	153.4	914.8	1351
Xe-prP6e	47.38	20.49	193.0	820.1	0	326.9	2842	4804

[1]- [3], [2]-[4], [3]- used in calculations 15.83