ОБЪЕДИНЕННЫЙ
ИНСТИТУТ
ЯДЕРНЫХ
ИССЛЕДОВАНИЙ

Дубна

E15 - 5800

M. Dakowski

IMPLICATIONS OF THE HYPOTHESIS OF EXTINCT FISSIONING ISOTOPE IN THE PRIMITIVE METEORITES

E15 - 5800

M. Dakowski*

IMPLICATIONS OF THE HYPOTHESIS OF EXTINCT FISSIONING ISOTOPE IN THE PRIMITIVE METEORITES

Submitted to "Physics Letters"

* On leave of absence from the Institute for Nuclear Research, Swierk near Warsaw, Poland.

Intention of the present paper is to draw attention of physicists, dealing with SHE, to the fact that taking into account the existing astrophysical and meteoritical data one can predict some properties of SHE.

1. Two Types of Fissiogenic Xe in Meteorites

Considering the isotopic composition of xenon in meteorites it seems unavoidable to take into account two distinct fission-like spectra of heavy isotopes of xenon (see, e.g. /1,2/). One of them, the so-called "Pasamonte type" (present mainly, but not exclusively, in the Ca-rich achondrites) was recently proved, with excellent conformity, to have the ^{244}Pu origin /3/. The fission-type xenon in carbonaceous chondrites (CC) and unequilibrated ordinary chondrites (UOC) differs from the "Pasamonte type" Xe. The amount of CC xenon is much greater than that of fissiogenic xenon in achondrites. It has a different spectrum and does not correlate with U and Th, but with volatile elements (e.g. Xe, In, Hg /4/). Therefore, these Xe anomalies have to be ascribed to quite different sources.

Although this effect might be accounted for by other mechanisms (Manuel and Kuroda [5] try to explain it by the mass fractionation), it can also be interpreted as an evidence for spontaneous fission of SHE [4,6]. These elements are the only candidates among the long-lived fissioning elements (both known, i.e. actinide, or predicted) to be the progenitor of this Xe.

Basing on the similarity of fission Xe spectra for different chondrites (having different history and mineralogical composition) and on the correlation between fission xenon ($_f$Xe) and fission krypton [7] one can assume as a progenitor of these anomalies a single fissioning isotope or isotopes with equal half-lives. This second possibility seems to be less probable. If the above assumption does not work, the noble gas anomalies would be different for chondrites with even small differences in the times of beginning of gas retention, because of the yield differences of Xe and Kr for different fissioning isotopes. The weighted average of the CC spectrum from the available results [8,9,10,1] is shown in Table 1.

2. Estimation of the Half-Life of SHE Isotope in Primitive Chondrites

As it was pointed out in ref. [6], the overall probability of fission for SHE is close to 1 as compared with ≈ 6×10^{-7} for ^{238}U fission and 1.26×10^{-3} for ^{244}Pu fission (using $T_{1/2} = (8.27 \pm 0.10) \times 10^{7}$ y on the basis of [11]). For the maximum amount of $^{136}_{f}Xe$ in CC ($^{136}_{f}Xe / ^{238}U \approx 6 \times 10^{-5}$) Anders and Heymann [4] obtained the ratio of $(SHE/U)_0 \approx 6 \times 10^{-4}$ at the beginning of Xe retention. They deduced the minimum half-life of this isotope equal to 2.1×10^{6} y.

Let us concentrate now on the maximum half-life for this isotope. At first let us assume that it has a half-life comparable or higher than ^{244}Pu, but not higher than $\approx 4 \times 10^9$ y. As it was pointed out in /2/ and /4/, $^{136}_{f}Xe$ in chondrites correlates with primordial ^{132}Xe. From fig. 1 in /4/ follows that $^{136}_{f}Xe / ^{132}Xe \approx 1.5\%$. The primordial ^{132}Xe is ~3 times more abundant than primordial ^{136}Xe, so we can estimate $^{136}_{f}Xe / ^{136}_{prim.}Xe \approx 5\%$. To extrapolate this correlation for achondrites it is necessary to assume small chemical fractionation between the parent nuclide of fission Xe and primordial Xe in the bulk of achondritic material. This assumption is substantiated by the In amount in the Ca-rich eucrites /12/ which correlates with ^{132}Xe in the same fashion as it does for chondrites, see fig. 3 of /4/ (0.24 and 1.6 ppb of In /12/ compared with 17 and 3.1×10^{-11} cm^3 CTP/g of ^{132}Xe /31/ for Stannern and Juvinas, respectively).

So on the basis of the assumption of a long half-life for SHE one would expect "CC type" fission spectrum in achondrites in the same proportion (5% of primordial ^{136}Xe) mixed with ^{244}Pu fission Xe. The share of this hypothetical CC fission would be highest for Pasamonte as this meteorite has the highest ratio of primordial to fission Xe as compared with St.-Severin whitlockite /16/ and Kapoeta extra dark /17/. The amounts of primordial ^{136}Xe for two Pasamonte samples /14,15/ allow to estimate the average amount of hypothetical "long-lived SHE" $^{136}_{f}Xe$ to be 13% of all the ^{136}Xe in these samples. In Table 1 (after /17/ and /3/) achondrite fission Xe spectra from different meteorites are compared with the ^{244}Pu spectrum /3/ and with the mixed spectrum obtained using the above-mentioned prescription. The weighted average of the Pasamonte type spectra is included for comparison. One can see that all the Pasamonte-type values for $^{132}_{f}Xe$ and $^{134}_{f}Xe$ are higher than the corresponding mixed values. The agreement between different meteorite spectra seems to be better than that expected on the basis of the errors quoted. From Table 1 one can easily see that ^{132}Xe isotope is the most sensitive to the admixture of the hypothetical CC Xe . Comparison of its fission yield for ^{244}Pu (see Table 1) with the average value of it for Pasamonte-type spectrum and with the corresponding value for mixed spectrum shows that the probability of the presence of the CC Xe admixture is rather small.

The nondetectability of CC fission Xe in achondrites allows to estimate its maximum half-life to be shorter than that for ^{244}Pu . It gives the upper limit of SHE half-life of $\approx 6 \times 10^7$ y.

3. Do SHE Isotope Living Longer than "CC SHE" Exist?

By the same token the existence of a second isotope of SHE with the half-life of $6 \times 10^7 < T_{1/2} < 4 \times 10^9$ y is excluded as it would be detectable in different classes of meteorites and/or in the old terrestrial and lunar minerals (assuming production rate to be similar to "CC SHE" production rate).

Let us consider the third possible range of SHE half-life $T_{1/2} \gtrsim 4 \times 10^9$ y . Such an isotope could be undetectable in the analysis of Xe in meteorites as only a fraction of it would decay. Assuming again its production rate in nucleosynthesis (P_ℓ) is of the order of magnitude of the production rate of "CC SHE" (P_{cc}) one can estimate the amount of this hypothetical long-lived SHE (at the end of nucleosynthesis and, as it does not decay considerably, in the present days) on the basis of the formula:

$$\frac{SHE_{\ell}}{SHE_{cc}} = \frac{P_{\ell} \cdot T_{\ell} \cdot (1 - e^{-t/T_{\ell}})}{P_{cc} \cdot T_{cc} \cdot (1 - e^{-t/T_{cc}})} ,$$

where t is the duration time of nucleosynthesis ($t \approx 10^{10}$ y) and T_{ℓ} , T_{cc} are the corresponding life-times of both isotopes.

Thus

$$\frac{SHE_{\ell}}{SHE_{cc}} \approx \frac{T_{\ell}}{T_{cc}} \gtrapprox \frac{4 \times 10^{9}}{6 \times 10^{7}} \approx 70 .$$

So the amount of such SHE_{ℓ} as compared with U would be $\geq 4 \times 10^{-2}$. Estimating the U abundance in the primitive matter to be not lower than the order of 10^{-8} g/g, the abundance of SHE_{ℓ} had to be higher than 10^{-10} g/g, even without taking into account the chemical enrichment in old minerals. If this isotope has a half-life comparable to that of ^{238}U , it would be detectable using track method in meteorites and in the old terrestrial minerals. For the ratio of fission to all the decays close to 1 and the abudance estimated above, the SHE tracks would dominate the U tracks by the orders of magnitude, which is not the case. In the last years even longer living isotope present in such an amount would be detectable in many laboratories by different methods. Let us look at some of the recent results.

Price et al. /18/ report for the fission of old minerals an apparent half-life relative to the principal component of the samples $T_{1/2} \gtrapprox 3 \times 10^{23}$ y. On the assumption that the half-life of SHE is 10^{9} y, the upper limit for SHE would be 3×10^{-15} g/g.

Cheifetz et al.[19] and Flerov et al.[20] report the apparent half-life $\gtrsim 10^{23}$ y for different minerals of volatile elements (using large fission neutron detectors and assuming for the fission of SHE the average number of neutrons $\bar{\nu} \gtrsim 4 \div 5$). These results are again incompatible with our estimation of the production rate for SHE. The alternative explanation of Dubna results for SHE would be $\bar{\nu} \lesssim 1.5$ [21]. Shukolyukov et al.[22] report no detectable admixture of non-uranium fission Xe in the old minerals. At last, Stéphan et al.[23] using the mass-separation and neutron activation in the mass range of 290-310, obtained directly the amount of SHE in their minerals to be lower than $10^{-12} \div 10^{-13}$ g/g. All these works were carried out on the minerals with a possible high enrichment in SHE.

4. Conclusions

Summarizing all these considerations one can state, using the estimated (on the basis of CC fission) production rate of SHE in the continuous galactic nucleosynthesis, that the most long-lived isotope of SHE is that manifesting itself in primitive chondrites.

It remains to be demonstrated that the CC fission-like spectrum is actually caused by fission. To substantiate this proposition the track method would be decisive. It is a pity that as yet the only two papers devoted to the superheavy fission track search in meteorites have reported results on highly differentiated material which, on the basis of Xe considerations [4,6] should not contain the SHE fission tracks. Price and Fleischer [24] proved the nonexistence of SHE tracks in silicate inclusions of iron meteorites, and the recent work by Bhandari et al. [25] claims to find the SHE tracks in achondrites.

It follows from the above arguments that minerals constituting a low temperature fraction of primitive chondrites (matrix) are older in the sence of the gas retention than Ca-rich achondrites. The Rb-Sr age determinations of CC (/26/ using the data of /27/) yield value $(4.69 \pm 0.14) \times 10^{9}$ y as compared with $(4.39 \pm 0.26) \times 10^{9}$ y for Ca-rich achondrites /28/. The errors quoted seem to be the maximal ones, so this difference can be significant. It would be consistent with measurable amounts of radiogenic ^{129}Xe in chondrites as compared with small, if at all detectable, amounts of this ^{129}Xe in Ca-rich achondrites /29/.

For substantiating this conclusion one needs the more precise determination of relative $^{129}I-Xe$ ages of matrix in comparison with the ages measured for the high temperature minerals (ref. /30/). Measurement of the internal isochrone using Rb - Sr method for the matrix of different UOC would be of great value for settling this problem.

Acknowledgements. Thanks are due to Academician G.N. Flerov for his help and encouragement. I am greatly indebted to Drs. A.A. Yavnel and O. Eugster for stimulating discussions and to Dr. P. Pellas for helpful criticism.

References

1. R.O. Pepin, in Origin and Distribution of Elements; L.H. Ahrens, ed. (Pergamon, Oxford, 1968) p. 379.
2. M.W. Rowe, Geoch. Cosmoch. Acta, 32, 1317 (1968).
3. E.C. Alexander, Jr., R.S. Lewis, J.H. Reynolds and M.C. Michel. preprint of Univ. of Calif. 1971.
4. E. Anders and D. Heymann, Science, 164, 821 (1969).

5. P.K. Kuroda and O.K. Manuel, Nature, 227, 1113 (1970).
O.K. Manuel et al., J. Geophys. Res., 75, 5693 (1970).

6. M. Dakowski, Earth Planet. Sci. Lett., 6, 152 (1969).

7. M.N. Rao, Nucl. Phys., A140, 69 (1970).

8. J.H. Reynolds and G. Turner, J. Geophys. Res., 69, 3263 (1964).

9. K. Marti, Earth Planet. Sci. Lett., 3, 243 (1967).

10. O. Eugster, P. Eberhardt and J. Geiss, Earth Planet. Sci. Lett., 3, 249 (1967).

11. C.E. Bemis, Jr., J. Halperin and R. Eby, J. Inorg. Nucl. Chem., 31, 599 (1969).

12. R.A. Schmitt and R.H. Smith, in Origin and Distribution of Elements, L.H. Ahres, ed. (Pergamon, Oxford, 1968) p. 281.

13. K. Marti, P. Eberhardt and J. Geiss, Z. Naturforsch., 21 a, 398 (1966).

14. M.W. Rowe and D.D. Bogard, J. Geophys. Res., 71, 4183 (1966).

15. C.M. Hohenberg, M.N. Munk and J.H. Reynolds. J. Geophys. Res., 72, 3119 (1967).

16. G. J. Wasserburg, J.C. Huneke and D.S. Burnet, J. Geophys. Res., 74, 4221 (1969).

17. M.W. Rowe, Geoch. Cosmoch. Acta, 34, 1019 (1970).

18. P.B. Price, R.L. Fleischer and R.T. Woods, Phys. Rev., C1, 1819 (1970).

19. E. Cheifetz et al., Proc. of the Conf. on Nuclei Far from the Region of Beta-Stability, Leysin, vol. 2, p. 709 (1970).

20. G.N. Flerov et al., Proc. of Heavy Ion Conf. Dubna, February 1971.

21. G.N. Flerov, ibid.

22. Ju.A. Shukolyukov, E.K. Gerling and G.S. Ashkenadze, ibid.

23. C. Stéphan, M. Sowiński, T. Czyżewski and J. Tys, ibid.

24. P.B. Price and R.L. Fleischer. Phys. Lett., 30B, 246 (1969).

25. N. Bhandari et al., Nature, 230, 219 (1971).
26. S.K. Kaushal and G.W. Wetherill, J. Geophys. Res., 75, 463 (1970).
27. S.K. Kaushal and G.W. Wetherill, J. Geophys. Res., 75, 3457 (1970).
28. D.A. Papanastassiou and G.J. Wasserburg, Earth Planet. Sci. Lett., 5, 361 (1969).
29. F.A. Podosek, Geoch. Cosmoch. Acta, 34, 341 (1970).
30. C.M. Hohenberg, F.A. Podosek and J.H. Reynolds, Science, 156 233 (1967).
31. P.K. Kuroda, in Radioactive Dating and Low-Level Counting, (IAEA, Vienna, 1967), p. 259.

Received by Publishing Department
on May 3, 1971.

Table 1.

Comparison of different fission yields of Xe.
(^{136}Xe normalised to 100).

Sample(-s)	References	fission yield		
		^{131}Xe	^{132}Xe	^{134}Xe
average of CC spectra	/1,8,9,10/	17 ± 7	31 ± 5	69 ± 3
^{244}Pu	/3/	24.6 ± 2.2	87.0 ± 3.1	92.1 ± 2.7
Pasamonte	/13/ from data of/14/	33 ± 3	93 ± 8	91 ± 2.5
Pasamonte	/15/	25 ± 3	88.5 ± 3	94 ± 5
whitlockite from St.Severin	/16/	31 ± 8	97 ± 8	93 ± 1
Kapoeta extra dark	/17/	26 ± 3	88 ± 4	91 ± 5
average of Pasamonte-type spectra	/13,15,16,17/	28.1 ± 1.7	89.3 ± 2.2	92.7 ± 0.9
CC(13%) + ^{244}Pu(87%) **spectrum**	this work	24 ± 4	80.5 ± 3.3	89.4 ± 3