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TIME DELAY BETWEEN THE NUCLEOSYNTHESIS OF COSMIC RAYS AND THEIR ACCELERATION TO RELATIVISTIC ENERGIES

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The time delay δt between the nucleosynthesis of the elements observed in the cosmic rays and the onset of their acceleration is of critical importance for the discussion of the origin of the cosmic radiation and will affect its composition. We invoke the Fe, Co and Ni isotopes to illustrate this point.

The presence of iron group nuclei in the galaxy is believed to be mainly due to explosive nucleosynthesis. This process does not produce iron directly, but the proton rich progenitors ^{56}Ni and ^{57}Ni. If these isotopes survive the ejection from the exploding star they decay to their stable isobar. ^{57}Ni decays quickly to ^{57}Co, ^{56}Ni and ^{57}Co can only decay to ^{56}Fe and ^{57}Ni via electron capture with a half life of 6.1 days and 270 days respectively. If the cosmic rays are accelerated to relativistic energies quickly after their synthesis, these decay modes are prevented, leading to large differences in the Ni/Fe and Co/Fe ratio in the cosmic rays and the solar system abundances. From existing data on the nickel, cobalt and iron abundances in the cosmic rays we conclude that more than a few weeks and most likely more than a year elapses between the synthesis of the cosmic ray nuclei and their acceleration.

1. Origin of Fe, Co and Ni. The more abundant isotopes of iron and nickel are supposed to be created in the explosive burning of a single dense shell of low neutron excess η (Hainebach et al. 1974). This low η zone throws out pure Ni since ^{56,57}Fe are preferentially synthetised as ^{56,57}Ni and explosively ejected. Because of their common origin we may expect that the subsequent dynamical history of these nuclei is the same. During the expansion the composition of the ejecta changes due to nuclear decay of unstable species.

Fig. 1 shows the evolution of the composition of the ejecta. The lifetimes of unstable nuclei have been estimated to be close to their lifetimes in the laboratory, on the basis of an idealized model of expansion (Cassé and Soutoul, 1975).

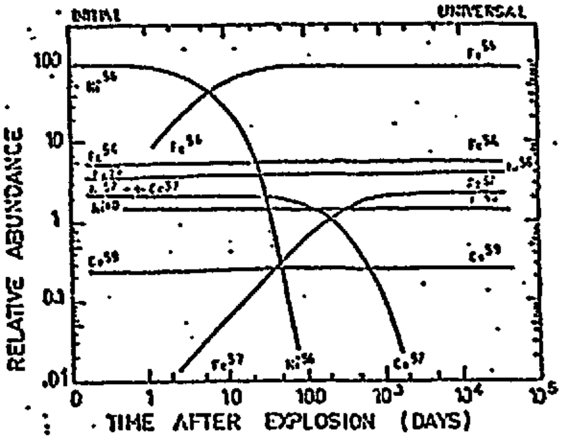

Fig. 1. Evolution of the nuclear composition as a function of time

Pure electron capture nuclei could be stabilized by a violent acceleration to cosmic ray energies. If cosmic rays are accelerated in the expanding envelope the primordial composition of Fe-peak nuclei must depend critically on the time δt elapsed between their genesis and their acceleration (Reeves, 1973, 1974). Possible selective acceleration effects (Cassé and Goret, 1975) (Kristiansson, 1974) do not affect the triad Fe-Co-Ni since those elements have about the same first ionization potential, similar ionization cross section by electrons and little difference in the nuclear charge.

In this paper, we predict the composition of the arriving cosmic rays for different δt and compare with the observations.

2. Predictions. Fig. 2 shows the abundances of Fe, Co and Ni in cosmic rays as a function of the time delay between the explosion, and the cosmic ray acceleration. The composition of the cosmic rays at the source, is assumed to be the same as the composition of the ejecta at the time of the acceleration, and the cosmic rays are propagated through 6.3 g/cm^2 of interstellar medium. It is assumed that the pathlengths are exponentially distributed, and we take the cross section for producing cobalt out of nickel to be 57 mb.

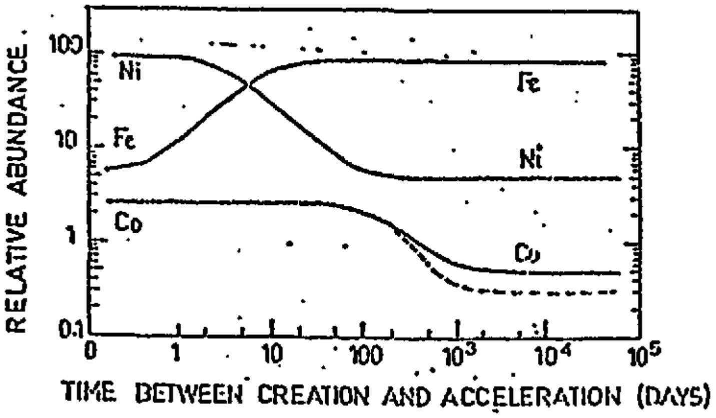

Fig. 2. Elemental abundances in the arriving cosmic radiation.

The origin of ^{59}Co is still debated (Hainebach et al. 1974). In fig. 1 we assume that ^{59}Co is created directly. If ^{59}Co is created as ^{59}Ni (Woosley, Arnett and Clayton, 1973), the ^{59}Co abundance on fig. 1 would be zero, and the abundance of Co in the arriving cosmic rays would be as shown by the dashed line in fig. 2, since ^{59}Ni cannot decay in the relativistic cosmic rays. However if the acceleration of the cosmic rays takes place more than 8.10^4 years after explosion, ^{59}Ni will have decayed at the source, and there would still be about 0.25 percent abundance of ^{59}Co in the iron group.

3. Observations. The abundances of iron, cobalt and nickel have been measured in a balloonborne instrument (Juliusson and Meyer, 1975). Fig. 3 shows a matrix of the responses obtained in two counters in that instrument. Cobalt is not fully separated from the iron and nickel peaks, and the charge overlap from iron and nickel is the dominating source of error. At the lower energies where the resolution is best this charge overlap error is however not much larger than the statistical error. The result obtained is Co/Fe = 0.007 ± 0.005 and Ni/Fe = 0.046 ± 0.006. These measurements are made at 6.0 g/cm^2 in the atmosphere, and correspond to an average energy of about 1.2 GeV/nucleon at the top of the atmosphere. We have calculated the atmospheric corrections for Co/Fe and Ni/Fe to be - 0.002 and + 0.001 respectively. The corrected results are thus : Co/Fe = 0.005 ± 0.005 and Ni/Fe = 0.047 ± 0.006.

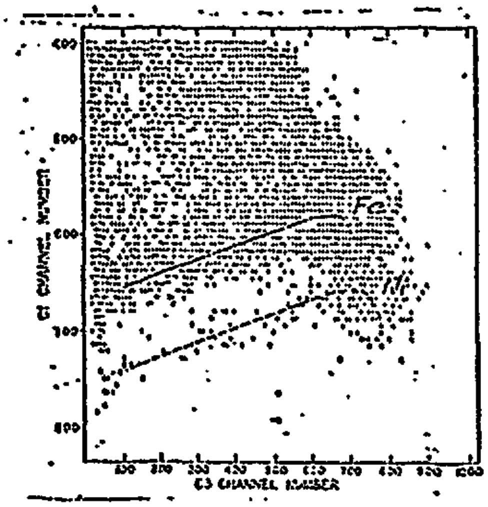

Fig. 3. Bidimensional representation of the responses of the instrument.

Israël et al. (1973) have measured the abundances of Co and Ni with a very large instrument. Again the cobalt is not fully separable from iron and nickel, and the charge overlap error is the main source of error for the cobalt abundances. Their preliminary results are (Israël, 1975), Co/Fe = 0.014 ± 0.004, or possibly lower, and Ni/Fe = 0.050 ± 0.004. These values are we believe not corrected for atmosphere, making the final value for Co/Fe = 0.012 ± 0.004.

Arens et al. (1975) have reported results for Co/Fe = 0.008 ± 0.002 and Ni/Fe = 0.042 ± 0.007. These values are in excellent agreement with the other results . We feel however that they may have underestimated the error on the cobalt abundances. The much larger error on the Ni/Fe ratio suggests that an error is included due to possible misassignment of charge. This charge overlap error would be as large for cobalt as for nickel.

All the results agree that the Ni abundances are about 5% of the iron abundances, showing an acceleration delay of at least a few weeks. They also all give Co/Fe values consistent with ^{57}Co having decayed i.e. time delay of more than a few years. Although cobalt is a difficult element to measure, and the error on its abundance is therefore large one must consider that these three results combined are inconsistent with an acceleration time delay of less than 1 year.

4. Conclusion. Assuming that cosmic rays are created with the bulk of the matter, the elemental Fe, Co and Ni abundances seems inconsistent with an acceleration time delay of less than one year.

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