Cloud Chamber reaction rate estimate.

Most low energy nuclear reactions wouldn't happen without tunneling, so just the physical size of the nucleus and the distance of closest approach are not necessarily good guides to the rate at which a reaction will take place.

The basic relationship for the rate *R* of any reaction where the target is thin (that is, formally, that the energy and therefore the physics is basically constant over the target) is

$$R = In\sigma x.$$

Here, *I* is the rate of incident particles, *n* is the number density of targets and *x* is the thickness of the target and σ is the cross section for the reaction. All the physics is in the cross section. More useful here is the rate per rate of incident particles:

$$\frac{R}{I} = \sigma n x$$

For an air cloud chamber *n* is just about $2.6\text{x}10^{19}$/cc. For now we will take the thickness as the range of the alpha particles (this is wrong b/c sigma is generally energy dependent, but this will usually give us an upper limit on the rate and we can fix it later).

The range of the alphas is energy dependent (and different sources will have different energies, usually in the range of 4-6 MeV, sometimes up to nearly 8 MeV ($^{214}$Po ==Radium C') ). The alpha ranges (in areal density) in different materials can be found here:

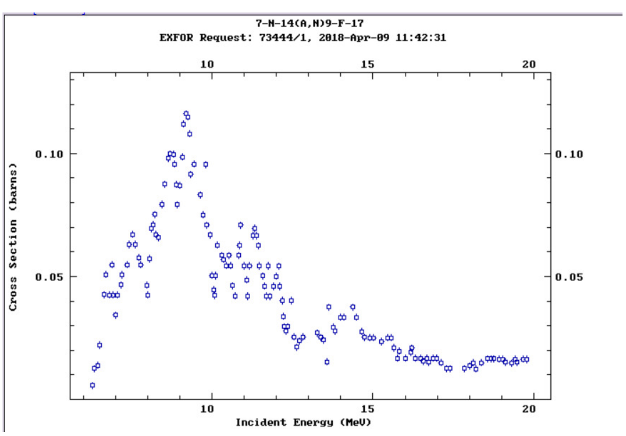
https://physics.nist.gov/PhysRefData/Star/Text/ASTAR.html

For air this give 3-9 mg/cm^2 from 4-8 MeV which at STP would be about 2.3 to 7 cm.

So then R/I =($6\text{x}10^{19}$ to $18\text{x}10^{19}$ /cm$^2$ ) x σ

Where sigma can be found from the NNDC site: http://www.nndc.bnl.gov/exfor/exfor.htm

For $^{14}$N(alpha,n)$^{17}$F the cross section vs energy is:




Where a barn is $1\text{x}10^{-24}$ cm$^2$

If we had 8 MeV alphas, then the cross section there is about 50 mb and the R/I would be $9x10^{-6}$. So for each alpha there's about a $9x10^{-6}$ chance of this reaction happening. Inverting that, it's about 1 in 100,000. Since half the emitted alphas will go into the source holder and not into the gas, there's another factor of 2 at least, so 1:200,000.

If we have a 1uCi source that would be $3.74x10^4$ decays per sec. That would be a lot for most an alpha source. 0.01 uCi would be more typical (e.g. Spectrum Techniques $^{210}$Po needle source for cloud chambers--(though $^{210}$Po has a 5.3 MeV alpha so we get no rate due to low cross section)) for 374 alphas per sec. So that would say maybe 374/200,000 = .002 reactions per sec (1 every 9 minutes).

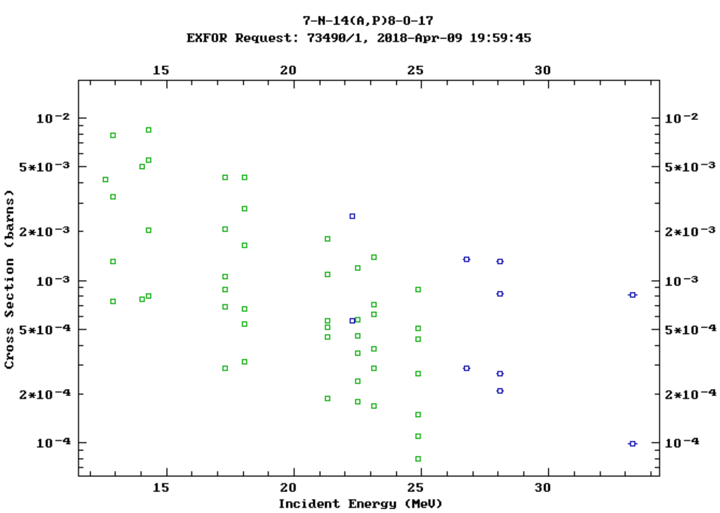
But, as you can see, the cross section is dropping like a rock at lower energies (this is a result primarily of the fact that tunneling through the coulomb potential barrier is involved—the tunneling probability changes rapidly with nearest approach distance which is limited by coulomb repulsion). Therefore, as the alpha loses energy, the probability of a reaction happening is dropping rapidly. For this reaction, it is basically zero below about 6 MeV.

Again, a rough estimate would be that the rate would be reduced by the smaller energy range over which reactions are taking place (2MeV/8MeV) and the fact that the average cross section over those 2 MeV is about ½ as big. Together that means losing a factor of 1/8 in rate so at best about 1 event per 72 minutes.

As mentioned, this was for 8 MeV alpha. The radium 226 chain (in equilibrium—which it might be in a natural ore sample, but probably not in a prepared source since $^{226}$Ra has a long lifetime) has some 7.7 MeV alphas from $^{214}$Po, but this is uncommonly high. Most sources are in the 4-6 MeV range and therefore have a negligible cross section for this reaction.

Addendum:

Another reaction is 14N(a,p)17O for which not as much cross section data are available. I was able to find this:




which indicates that there's not much data below 13 MeV and where there is data, the cross section is about 5x smaller. It's not always clear what happens at lower energies, unless there's a resonance, I would expect it to go down as energy goes down due to the coulomb repulsion/tunneling aspect of the cross section.