ISAAC ASIMOV

# ONLY A TRILLION

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*To*

GERTRUDE

*again*

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# INTRODUCTION

ONE of the stories my mother likes to tell about me as a child is that once, when I was nearly five, she found me standing rapt in thought at the curbing in front of the house in which we lived. She said, 'What are you doing, Isaac?' and I answered, 'Counting the cars as they pass.'

I have no personal memory of this incident but it must have happened, for I have been counting things ever since. At the age of nearly five I couldn't have known many numbers and, even allowing for the relatively few cars roaming the streets thirty years ago, I must have quickly reached my limit. Perhaps it was the sense of frustration I then experienced that has made me seek ever since for countable things that would demand higher and higher numbers.

With time I grew old enough to calculate the number of snowflakes it would take to bury Greater New York under ten feet of snow and the number of raindrops it would take to fill the Pacific Ocean. There is even a chance that I was subconsciously driven to make chemistry my life-work out of a sense of gratitude to that science for having made it possible for me to penetrate beyond such things and take—at last—to counting atoms.

There is a fascination in large numbers which catches at most people, I think, even those who are easily made dizzy.

For instance, take the number one million; a 1 followed by six zeros; 1,000,000; or, as expressed by physical scientists, $10^6$, which means 10 x 10 x 10 x 10 x 10 x 10.

Now consider what 'one million' means.

How much time must pass in order that a million seconds may elapse?—Answer: just over 11½ days.

What about a million minutes?—Answer: just under 2 years.

How long a distance is a million inches?—Answer: just under 16 miles.

Assuming that every time you take a step your body moves forward about a foot and a half, how far have you gone when you take a million steps?—Answer: 284 miles.

In other words:

The secretary who goes off for a week to the mountains has less than a million seconds to enjoy herself.

The professor who takes a year's Sabbatical leave to write a book has just about half a million minutes to do it in.

Manhattan Island from end to end is less than a million inches long.

And, finally, you can walk from New York to Boston in less than a million steps.

Even so, you may not be impressed. After all, a jet plane can cover a million inches in less than a minute. At the height of World War II, the United States was spending a million dollars every six minutes.

So—— Let's consider a trillion. A trillion is a million million[1]; a 1 followed by 12 zeros; 1,000,000,000,000; $10^{12}$.

A trillion seconds is equal to 31,700 years.

A trillion inches is equal to 15,800,000 miles.

In other words, a trillion seconds ago, Stone Age man lived in caves, and mastodons roamed Europe and North America.

Or, a trillion-inch journey will carry you 600 times around the Earth, and leave more than enough distance to carry you to the Moon and back.

And yet a good part of the chapters that follow ought to show you quite plainly that even a trillion can become a laughably small figure in the proper circumstances.

After considerable computation one day recently I said to my long-suffering wife: 'Do you know how rare astatine-215 is? If you inspected all of North and South America to a depth of ten miles, atom by atom, do you know how many atoms of astatine-215 you would find?'

My wife said, 'No. How many?'

To which I replied, 'Practically none. Only a trillion.'

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[1] That is, according to American and French usage. In England, a billion is $10^{12}$ and a trillion is $10^{18}$, that is, zeros are counted in groups of six, not in groups of three as in America and France. The American custom will be followed in this book, when a billion will mean $10^9$ and a trillion $10^{12}$.

## CHAPTER ONE

# THE ATOMS THAT VANISH

I THINK I can assume that the readers of this book all know that there are atoms which are unstable and which break down by ejecting particles from within their nuclei. Sometimes the ejection of one particle is sufficient to allow what remains of the nucleus to be stable. Sometimes a dozen or more particles must be ejected one after the other in order for stability to be attained.

In either case, the original atom is completely changed.

If you were to focus your attention on a particular one of these unstable atoms, it would be impossible for you or for anyone to tell when it would explode and eject a particle. It might do so the very next instant; it might stay put for a million years before doing so.

Dealing with a large group of objects, however, is not the same as dealing with only one object. Once you have a large group, you can use statistics to predict the future. The larger the group, the more accurate (percentage-wise) the predictions.

Given enough atoms, statistics will predict, for instance, that after a certain particular length of time, half of a quantity of a certain unstable atom will be broken down. After the same length of time, half of what is left will be broken down. After the same length of time, half of what is *still* left will be broken down, and so on as long as any of the atoms are left at all.

Each kind of unstable atom has its own characteristic time for half-breaking-down. This time is called the 'half-life'.

Let's see what this involves in a particular case. Suppose we take a kind of atom we will call Atom X and suppose that it has a half-life of exactly one day; twenty-four hours on the nose. Let's suppose, further, that at noon on January 1, 1957, you have in your possession 1,048,576 atoms of Atom X. What will happen if statistical laws are followed exactly?

The simplest way of answering that question is to present a table. For that reason, you are invited to look at Table I.

TABLE I

| *Date (12 m.)* | *No. of Atoms of Atom X left* |
|---|---|
| January 1 | 1,048,576 |
| January 2 | 524,288 |
| January 3 | 262,144 |
| January 4 | 131,072 |
| January 5 | 65,536 |
| January 6 | 32,768 |
| January 7 | 16,384 |
| January 8 | 8,192 |
| January 9 | 4,096 |
| January 10 | 2,048 |
| January 11 | 1,024 |
| January 12 | 512 |
| January 13 | 256 |
| January 14 | 128 |
| January 15 | 64 |
| January 16 | 32 |
| January 17 | 16 |
| January 18 | 8 |
| January 19 | 4 |
| January 20 | 2 |
| January 21 | 1 |

Suppose that matters work out ideally and that we are down to a single atom by January 21. What happens to that atom? Statistics can't say exactly, but it can predict probabilities. For instance, the odds are even money that a single atom of Atom X will last one day or less and be gone by noon on January 22. The odds are 2 to 1 that it will be gone by noon on January 23; 4 to 1 that it will be gone by noon on January 24; and over a million to 1 that it will be gone by noon on February 11.

It's pretty safe to say, then, that of the more than a million atoms you started with at New Year's Day all would probably be gone within a month and almost certainly within six weeks.

A very important thing to remember, incidentally, is that it doesn't matter whether those million atoms of Atom X were heaped together in a pile to begin with, or scattered singly over the entire Earth. The end result is exactly the same either way.

But what if we were to begin with more than 1,048,576 atoms. Take an extreme case as an example. There are about $10^{50}$ atoms in the entire planet, Earth. (The number, $10^{50}$, is a shorthand way of writing a number which consists of a 1 followed by 50 zeros. In other words, $10^{50}$ is a hundred trillion trillion trillion trillion). We are going to suppose now that the entire Earth is composed of Atom X exclusively. How long would they last?

The answer is about 5½ months.

Of course, we don't have to stop with the Earth. It has been estimated that the number of atoms in the entire known Universe (including the Sun, the Moon, the planets, the stars and galaxies, the interstellar dust and gas) is about $10^{75}$. If every atom in the entire Universe were Atom X, the whole supply would be gone in about 8½ months.

So you see it is now possible to make a very comprehensive statement. When the Universe first came into being, a certain number of atoms of Atom X might have existed. If so, then *no matter how many of them existed*, not one of those original atoms of Atom X is left today.

But certain radioactive (*i.e.* unstable) atoms *do* exist today. If you have heard of no other examples, you have surely heard of uranium. The question, then, is under what conditions can radioactive atoms, formed at the time the Universe came into being, still exist today.

One way in which the existence of radioactive atoms can be stretched out is to have the individual atoms break down less frequently; that is, have longer half-lives.

To give you an idea of what the effect of half-life on atomic existence is, consider Table II. Such a table points out the fact that if the half-life is only long enough then the atoms will last as long as is desired.

Through several lines of evidence, astrophysicists have come to believe that some four or five billion years ago some kind of cosmic explosion took place, in the course of which the atoms, as we know them today, were formed. To have a round number, then, let us say that the Universe is five billion years old.

In a five-billion-year-old Universe, even atoms with half-lives of a thousand years (the longest considered in Table II)

TABLE II

| *If the half-life of an atom is . . .* | *Then a Universe-full of such atoms will last . . .* |
|---|---|
| 1 second | 4 minutes |
| 1 minute | 4 hours |
| 1 hour | 10 days |
| 1 day | 8 months |
| 1 week | 5 years |
| 1 month | 20 years |
| 1 year | 250 years |
| 1 decade | 2,500 years |
| 1 century | 25,000 years |
| 1 millennium | 250,000 years |

couldn't possibly have lasted to the present moment no matter how many had originally been formed. In fact, if we were to continue Table II onward to even longer half-lives, we would find that in order for even a single atom to be present today of a Universe-full of atoms five billion years ago, the half-life of those atoms would have to be twenty million years.

That's for a Universe-full. Actually, there could not have been that many radioactive atoms to begin with. Virtually all the atoms in the Universe are stable. It is extremely unlikely that more than one atom out of a billion was unstable to begin with (that is, after the first flush of creation had passed and short-lived atoms like Atom X had died out). If we restrict ourselves to that small proportion then in order for even one unstable atom to survive today, it must have a half-life of six hundred million years as absolute minimum.

If the half-life is greater than six hundred million years, or, preferably, much greater than that, then some of the atoms could be existing today. That answers my earlier question.

Few radioactive atoms have half-lives that long, but some do. The best known case, of course, is that of uranium. Uranium is made up of two types of atoms, uranium–238 and uranium–235. Uranium–238 is the more common of the two. Out of every thousand uranium atoms, taken at random, 993 are uranium–238 and only 7 are uranium–235.

Uranium–238 has an extremely long half-life, four and a half billion years. Uranium–235 has a shorter half-life (yet still not what one would really call short); it is a bit over seven hundred million years.

There are three other fairly common atoms (and several uncommon ones we won't mention) that fall into the same class as these uranium atoms. One is the element, thorium, which is made up of only one type of atom, thorium–232. It is even longer-lived than uranium–238. Thorium–232 has a half-life of fourteen billion years.

Then there is one of the varieties of potassium. Potassium is one of the most common elements in the Earth's crust, much more common than either uranium or thorium. It is made up largely of two kinds of atoms, potassium–39 and potassium–41, both of which are stable. One out of every ten thousand potassium atoms, however, is a third variety, which is potassium–40, and this variety is radioactive. The half-life of potassium–40 is about one and a fifth billion years.

Finally, there is rubidium. This element is much like potassium, but it is considerably rarer. Over a quarter of the atoms in rubidium, however, are a radioactive variety known as rubidium–87. This atom has the longest half-life I have yet mentioned; sixty-two billion years.

Now since we know the half-lives of these five types of atoms and since we have a figure for the age of the Universe, it is possible to calculate what percentage of the original quantity of each atom is still in existence today. The results are shown in Table III.

Naturally, the shorter the half-life, the smaller the percentage remaining today. Uranium–235, with a half-life close to the minimum allowed for survival, is well on the way toward disappearance. Five billion years ago, fully 280 out of every thousand uranium atoms were uranium–235. Now only 7 out of every thousand are.

These five kinds of atoms account for almost all the natural radioactivity of the Earth's crust. (The Earth's crust may be

TABLE III

| *Atom* | *Half-life* | *Out of every thousand atoms originally existing, there remain today . . .* |
|---|---|---|
| Rubidium–87 | 62,000,000,000 years | 950 |
| Thorium–232 | 14,000,000,000 years | 800 |
| Uranium–238 | 4,500,000,000 years | 540 |
| Potassium–40 | 1,200,000,000 years | 56 |
| Uranium–235 | 710,000,000 years | 8 |

defined as the ten-mile thick outermost layer of the Earth's solid surface.)

In Table IV, I present the latest data I can find for the occurrence of atoms of potassium, rubidium, thorium and uranium in the Earth's crust. Notice that potassium is by far the most common of these elements. However, it contains so few of the potassium–40 variety that there are actually fewer of those than there are of rubidium–87, which forms a larger percentage of a rarer element.

Merely the quantity of each atom, however, is not the whole story. There are over five and a half times as many rubidium–87 atoms in the Earth's crust as uranium–238 atoms, true. Yet uranium–238 atoms are breaking down at fourteen times the rate that rubidium–87 atoms are. Furthermore, while rubidium –87 ejects only a single particle before becoming stable, uranium –238 ejects no less than fourteen particles before reaching stability. For both these reasons, uranium–238 is responsible for many more of the flying sub-atomic particles that criss-cross the Earth's crust than is the more common rubidium–87.

In fact, making allowance for the rate of breakdown and the number of particles ejected in the course of breakdown, we can prepare Table V. The particles can be divided into two main groups, the 'alpha particles' (comparatively heavy) and the 'beta particles' (comparatively light). Figures for both particles are given in Table V.

TABLE IV

| *Element* | *Out of every billion atoms in the Earth's crust the number of atoms of this element is . . .* | *Variety of atom* | *Out of every billion atoms in the Earth's crust the number of atoms of this variety is . . .* |
|---|---|---|---|
| Potassium | 13,400,000 | Potassium-40 | 1,600 |
| Rubidium | 66,000 | Ribidium-87 | 1,800 |
| Thorium | 1,000 | Thorium-232 | 1,000 |
| Uranium | 320 | Uranium-238 | 318 |
|  |  | Uranium-235 | 2 |

Let's look at Earth's radioactivity in another way. In the Earth's crust there are roughly 6 x $10^{47}$ atoms (a 6 followed by 47 zeros) and of these about 3 x $10^{42}$ are our five radioactive varieties. If we consider all the radioactive atoms in the entire crust, it can be calculated that the total number of sub-atomic particles being shot out of atomic nuclei in the crust amounts to 2 x $10^{24}$ (or two trillion trillion) *every second*!

Undoubtedly, this number is too big to grasp, so we'll cut it down to size. Suppose the radioactivity of the Earth's crust

TABLE V

|  | *Out of every thousand particles released by radioactive breakdown . . .* |  |
|---|---|---|
| *Atom* | *the number of alpha particles released is . . .* | *the number of beta particles released is . . .* |
| Potassium-40 | — | 185 |
| Rubidium-87 | — | 12 |
| Thorium-232 | 195 | 135 |
| Uranium-238 | 270 | 190 |
| Uranium-235 | 8 | 5 |
| Total | 473 | 527 |

were evenly spread all over (which, of course, it isn't) and suppose you owned an acre of land. The top ten feet of your acre would weigh about 38,000 tons, and in it there would be two and a third billion particles shot out by radioactive atoms every second.

Still too big? Very well, then, consider a cubic foot of soil (about 170 pounds). If it contained its fair share of the radioactive elements, it would be bouncing to the tune of 5,000 particles ejected every second.

Despite the fact that uranium–235 is almost all gone, atoms of much shorter half-life exist on Earth. Radium, for instance. The longest-lived variety of that element, radium–226, has a half-life of only 1,622 years. This is far, far less than the six hundred million year minimum I set earlier as necessary for existence. Yet radium exists.

If this seems contradictory at first sight, remember that I have been supposing that atoms were created only at the time the Universe was formed. Any radium atoms that were formed then have, indeed, disappeared many eons ago. But why should we suppose that no radium atoms have been formed since the beginning of the Universe; why should we suppose that no radium atoms are being formed right now?

In fact, radioactive atoms can be formed and are being formed continuously. One natural method for producing unstable atoms in quantity involves cosmic radiation. This consists of extremely high-speed sub-atomic particles that originate from outside the Earth. They are the most energetic particles we know. They bombard Earth every second of the day and night. They plow into Earth's atmosphere and when they hit some atom in the atmosphere, that atom goes smash.

One quite interesting atomic change that takes place as a result is the conversion of occasional nitrogen atoms to an unstable variety of carbon called carbon–14. Carbon–14 has a half-life of only 5,570 years, but new formation by cosmic rays keeps pace with its breakdown and among the carbon dioxide molecules of the atmosphere, just over one carbon atom out of a trillion is carbon–14.

Cosmic radiation, however, has nothing to do with radium. To get to that, let's turn our attention again to the long-lived radioactive atoms: uranium–238, uranium–235, thorium–232, rubidium–87 and potassium–40.

Rubidium–87 and potassium–40 break down simply. Each eliminates a beta particle and is done. Having rid itself of a beta particle, the rubidium–87 atom becomes a strontium–87 atom which is stable; the potassium–40 atom becomes a calcium–40 atom which is also stable. The breakdowns are ended.

The breakdowns of uranium–238, uranium–235 and thorium –232, however, are more complicated affairs and in that complication rests the solution of our problem.

Take uranium–238, for instance. It breaks down by ejecting an alpha particle. In doing so, it forms the atom thorium–234. But thorium–234 is not stable. In fact, it is much shorter-lived than uranium–238 and has a half-life of only 24 days.

The thorium–234 atom breaks down by emitting a beta particle and becoming protactinium–234. But that is unstable, too, and has a half-life of less than seven hours. Protactinium–234 breaks down and so does the atom it becomes and the atom *it* becomes and so on. All told, uranium–238 breaks down through a total of 16 varieties of atoms before it finally becomes lead–206 (a stable atom) and comes to rest.

Uranium–235 goes through a similar process, breaking down through 13 varieties of atoms before becoming lead–207, a stable atom. Thorium–232 breaks down through 11 varieties of atoms before becoming lead–208, a stable atom.

These three series of atom varieties do not duplicate one another at any stage. Any variety of atom formed in one of the series is not formed in either of the other two. This means that a total of 40 different kinds of radioactive atoms are produced during the breakdown of uranium–238, uranium–235 and thorium–232.

All 40 descendant atoms are continually breaking down but are also continually being produced, so all 40 exist on Earth wherever uranium and thorium are found, and will exist as long as uranium and thorium do. One of the 16 kinds of radioactive atoms formed from uranium–238 during its breakdown is radium–226 and that is why radium–226 still exists on Earth and will continue to exist unless mankind consumes all Earth's uranium in nuclear power plants.

The next question is, how much of these short-lived radioactive atoms exist on Earth as a result of uranium and thorium breakdown. It turns out that the ratio of quantity of a 'descendant' atom and its 'parent' is the same as the ratio of the half-lives.

Let's take an actual case. Uranium–238 has a half-life of four and a half billion years. Thorium–234, its first descendant atom, has a half-life of 24 days. The half-life of uranium–238 is thus sixty-eight billion times as long as that of thorium–234; therefore, there is one atom of thorium–234 present in the Earth for every sixty-eight billion atoms of uranium–238. It's as straightforward as that.

Once in a while, it happens that a radioactive atom can break down in two different ways. For instance, the radioactive bismuth–212 atom (which is one of the descendants of thorium–232) can lose an alpha particle to form thallium–208, or it can lose a beta particle to form polonium–212. For every three bismuth–212 atoms that break down, one polonium–212 atom and two thallium–208 atoms are formed. Whenever such 'branching' occurs, this must also be taken into account in determining the quantity of descendant atoms present in the Earth.

When the total amounts of the various descendant atoms are calculated, it turns out that many are present in comparatively trifling amounts. Still, each of the three parent atoms, uranium–238, uranium–235 and thorium–232, has at least two descendants that do fairly well and are present in the ratio of at least one atom for every ten billion of the parent. These descendants are listed in Table VI.

As you can see, uranium–234 is the most long-lived of these descendants. It is so long-lived (with a half-life of a quarter of a million years) that it piles up in uranium–238 to the point where there is one atom of uranium–234 for every 18,000 atoms of uranium–238. In other words, there is one atom of uranium–234 for every 130 atoms of the much longer-lived uranium–235.

The total number of atoms in the Earth's crust is, as I said

TABLE VI

| *Atom* | *Half-life* | *For every ten billion atoms of uranium–238, there are . . .* |
|---|---|---|
| Uranium–234 | 248,000 years | 550,000 atoms |
| Thorium–230 | 80,000 years | 175,000 atoms |
| Radium–226 | 1,622 years | 3,620 atoms |
| Lead–210 | 22 years | 49 atoms |
| | | *For every ten billion atoms of uranium–235, there are . . .* |
| Protactinium–231 | 34,300 years | 485,000 atoms |
| Actinium–227 | 22 years | 310 atoms |
| | | *For every ten billion atoms of thorium–232, there are . . .* |
| Radium–228 | 80 months | 5 atoms |
| Thorium–228 | 20 months | 1½ atoms |

earlier, 6 x $10^{47}$. From that and from other data given earlier, we can calculate the total number of atoms of uranium–238, uranium–235 and thorium–232 in the Earth's crust. Having got so far, we can then determine the number of atoms present for any of the descendants. What's more, knowing the number of atoms of any substance, it is possible to calculate the corresponding weight and that is given in Table VII.

As you see from Table VII, it turns out that through the normal processes of the radioactive breakdown of uranium–238, the supply of radium–226 in the Earth's crust amounts to over twenty-eight million tons. A ton of radium–226 (assuming it to be five times as dense as water) takes up about six and a half cubic feet. The total quantity of radium in the Earth's crust is therefore 184 million cubic feet. If this were spread evenly over an area the size of Manhattan Island (which is 22 square miles in area), it would cover it 3½ inches deep.

TABLE VII

| *Atom* | *Quantity present in the Earth's crust* |
|---|---|
| Thorium–232 | 255,000,000,000,000 tons |
| Uranium–238 | 83,000,000,000,000 tons |
| Uranium–235 | 575,000,000,000 tons |
| Uranium–234 | 4,300,000,000 tons |
| Thorium–230 | 1,400,000,000 tons |
| Radium–226 | 28,300,000 tons |
| Protactinium–231 | 10,000,000 tons |
| Lead–210 | 545,000 tons |
| Radium–228 | 126,000 tons |
| Thorium–228 | 39,000 tons |
| Actinium–227 | 6,600 tons |

Of course, far less radium is actually available to mankind. We can only dig through the topmost layers of the crust and only in certain parts of Earth's land area. At most, only one or two per cent of the crust is available to us and even there the radium–226 is spread so thinly that it is a Herculean task to scrape even a small fraction of an ounce together.

In Table VII, I considered only the long-lived parent atoms and their comparatively long-lived descendants. Even the least of the atom varieties mentioned is present in the Earth's crust in the thousands of tons. However, there are 31 varieties of descendant atoms that are not mentioned in Table VII. What of them?

To get the other end of the picture, I'll begin by listing descendant atoms with very short half-lives in Table VIII.

The half-lives of some of these atoms are so short that the second becomes an inconveniently long time interval to use as a measure. The microsecond (one-millionth of a second) is handier. It seems much more casual and neat to say that the half-life of astatine–215 is 100 microseconds than to say that it is one ten-thousandth of a second. Even a microsecond is none too small. Polonium–212 has a half-life that is only about a third of a microsecond and it isn't a record-breaking example by any means.

The short half-lives are not the only things that make the atoms listed in Table VIII rare. Most of them are formed through branched breakdowns of their parent atom, usually on the short side of the branch. For instance, thallium–206 is formed through the breakdown of bismuth–210. Bismuth –210, however, also breaks down to form polonium–210. But out of every 10,000,000 bismuth–210 atoms that break down, 9,999,999 turn into polonium–210 and only 1, just 1, becomes thallium–206.

TABLE VIII

| *Atom* | *Half-life* |
|---|---|
| Francium–223 | 20 minutes |
| Thallium–206 | 4·2 minutes |
| Astatine–218 | 2 seconds |
| Polonium–216 | 0·16 seconds |
| Polonium–211 | 0·005 seconds (or 5,000 microseconds) |
| Polonium–215 | 0·0018 seconds (or 1,800 microseconds) |
| Astatine–216 | 0·0003 seconds (or 300 microseconds) |
| Polonium–214 | 0·00015 seconds (or 150 microseconds) |
| Astatine–215 | 0·00010 seconds (or 100 microseconds) |
| Polonium–212 | 0·0000003 seconds (or 0·3 microseconds) |

If the short half-life is taken into account and also whatever short-changing the various atoms may have had in the way of branched breakdowns, it is possible to calculate the weight of each variety of atom present in the Earth's crust. This is done in Table IX.

You can see it is no longer a question of tons at all. Except

TABLE IX

| *Atom* | *Amount in the Earth's crust* |
|---|---|
| Francium–223 | 10 ounces |
| Polonium–216 | 2·8 ounces |
| Astatine–218 | 0·014 ounces |
| Polonium–211 | 0·0032 ounces |
| Polonium–214 | 0·0026 ounces |
| Polonium–215 | 0·0013 ounces |
| Thallium–206 | 0·00041 ounces |
| Polonium–212 | 0·0000045 ounces |
| Astatine–216 | 0·00000073 ounces |
| Astatine–215 | 0·0000000032 ounces |

for two of the atom varieties, it isn't even a question of ounces, but of fractions of ounces. Astatine–215 is worst off. Not only has it a short half-life (100 microseconds), but it is formed from uranium–235, which is the least common of the three parent atoms. To top it off, astatine–215 is at the short end of a 200,000 to 1 branching breakdown. The result is that in the entire crust of the Earth, there is less than a billionth of an ounce of astatine–215. If it were all gathered together in one spot, it wouldn't be enough to see with the naked eye.

Consider once again the acre of land ten feet deep I mentioned earlier in this chapter. That amount of soil would contain something like $10^{33}$ atoms (a billion trillion trillion). If all the various atoms in the Earth's crust were spread evenly throughout, you would find in your acre of land, three hundred trillion trillion atoms of uranium and one trillion trillion atoms of gold. (That's right, gold is much rarer than uranium.) There would be a little over a billion atoms even of francium–223.

The chances, however, would be 30 to 1 against there being even a single atom of astatine–215 present.