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UNDERSTANDING ATOMIC ENERGY

14 April 1948

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COLONEL VANAMAN: Gentlemen, down through the ages man has found that a diet of bread and meat is not conducive to a full life; so man developed the dessert. He developed the cream puff type and developed the robust, flaming, plum pudding type. Now we are studying manpower and we are finding that just plain bread and meat are not enough. So we are injecting into the course today a dessert; and I will assure you it is not the cream puff type. It is the flaming, plum pudding, robust type of dessert.

Mr. Ward needs no introduction to this school. He has been a friend of the school for a long time. So today we are going to figuratively and literally sit on the edge of our seats listening to Mr. J. Carlton Ward, of the Fairchild Engine and Airplane Corporation. Mr. Ward.

MR. WARD: Gentlemen, I think we had better start off by getting ourselves squared away on some fundamentals. The first and very obvious one is that you won't be long discovering that I am not a scientist. Years ago I had an engineering education, and there are times when that devils me a little bit and I still think I can think like an engineer. So actually we are pretty much on a plane, most of us, because, even though there are no doubt people among you who are really familiar with this subject, I am going to assume that for the most part we here today are not scientists, that we are a little hazy on our engineering. So I will try to bring this subject down to the comprehension of all of us.

I think if I can accomplish one thing, enough will have been accomplished for the day. That one thing is to bring to all of us these facts: That atomic energy is not something that can be understood only by the Einsteins; and, furthermore, that it is something that is going to affect the lives of each one of us and certainly the lives of our children.

I personally believe that the year 1896, which we will discuss a little more later on, will be a year that will be studied by school children for thousands of years yet to come, or for millions of years, or, if you believe the theory of genes, for the billions of years during which the earth will still provide a suitable habitation for people like us, or whatever our descendants turn out to be under the Darwinian theory, which again you will find to be traceable to variations in inheritance that are influenced by atomic energy. That sounds a little fantastic, but you know that scientists can change the sex of fruit flies by X-rays, by physiochemistry, by nucleonics, or whatever term you have to coin for these new things. There is a theory that new traits of character appear perhaps because of cosmic rays that wander around and happen to hit that little delicate mechanism of inheritance which we call the gene. You see I am already off my subject. I had better get back to it.

Remember that when the report of that flight was sent out, the New York Times refused to publish it, because it was too fantastic. Only a few papers would publish the fact that man had successfully accomplished a controlled flight in the air. That was 1903.

So the only point to this timetable idea is to bring out clearly in your mind the fact that man is still in his infancy. To make that a little more dramatic, let me say this: Sir Arthur Eddington, the great British astronomer, has calculated the length of life of the earth from here on, and he figures that it is about 500 billion years. If it is anything approaching that, you can easily appreciate that we have not even started on the earth. Where will atomic energy be in the year 2 billion, 20 billion, or 200 billion from now? When you start now by thinking back on where aviation has gone since 1903, you can just imagine where atomic science is going to go in the next forty or fifty years.

I have put 52 years ago as the birthday of atomic science. Now I would like to get right down to cases and discuss what has happened to atomic science since its birthday.

We will write "1896" on this blackboard as the date when Becquerel of France stumbled on atomic science. I say "stumbled" because most of our great discoveries are made accidentally. He had in the bottom of a cabinet in his laboratory some pitchblende, a uranium-radium ore. He was experimenting with it. There was a drawer in his cabinet in which there was a very heavy bronze key, and on top of his cabinet he had some unexposed glass photographic plates. When he went to use the plates, he found that there was a picture of the key on them, although they had not been used nor had they been near the key. Being a scientist, he went to work and by fooling around he found that if he took the ore out of the bottom of that cabinet, the picture of the key would not appear on the plates. So he then said, "There is something funny about that ore."

Now, the next date in our timetable is 1898. In that year the Curies took that ore and fooled with it chemically and isolated radium. In two years they had extracted radium from the ore that had brought the key to life on the plates. When they discovered that radium principle, they discovered a new phenomenon. In other words, radium apparently went on giving off energy, giving off these penetrating rays, but nothing much changed about the radium. They couldn't find any difference in weight, couldn't find any difference in character; and yet all the chemistry that was known up to 1898 indicated that if you had an exothermic reaction, as they call it, which is a heat-giving reaction, sooner or later the thing runs down, it quits giving out heat, quits giving out radiation. Well, in time they discovered that loss of radioactivity proceeds according to a law which is called the half life. I am going to define that very briefly, because it is very fundamental in this thing.

old alchemists who used to try to make gold out of mercury. To the atomic scientists it is perfectly possible to make gold out of mercury, and it is perfectly possible to make mercury out of gold: but this was the man who discovered that method or process, and this was in 1919. It is obvious that the scale on which he did it was so fantastically small that only the most delicate instrument could show that he had done it. It was not a commercial process, or you would see a big factory within the Fairchild organization making gold out of mercury.

The next date we might put down here is 1934, when a British physicist named Chadwick, a very young fellow, did a remarkable thing. He discovered the neutron. The reason that is particularly remarkable is because the neutron bears no electrical charge, and it is so small that it is less than a wave length of light in size. You can't see it. Since it has no electrical charge, you can't push it around with electro-magnetic or electrostatic fields. The usual methods of exploration therefore were not available; so he did some of the shrewdest work that has ever been done to prove the existence of something that didn't want to be brought out before the public.

Now, the next discovery that came along was in 1938, when two Germans, Hahn and Strassmann, performed an experiment in a cyclotron and got a result that no one had ever anticipated. They discovered atomic fission. But they didn't know what it was. That is what saved us in the war. It was their lack of interpretation of what they had discovered that allowed the news of fission to get out to England and the United States and the other allied countries. Scientists have this beautiful form of underground intelligence that goes all over the world. They cooperate on scientific discoveries. Had that discovery been bottled up by the Germans, we might not have won the war. But Hahn and Strassmann thought this was just a scientific freak that they saw in the cyclotron and so they told everybody about it.

Actually this is what it was: They fired one of these little atomic projectiles at the nucleus of an atom; and instead of bumping the nucleus out of place and measuring how far the bumped piece went because of the bump, doing that analytically by the ordinary laws of mechanics that can reduce the relative masses of two particles--a method that physicists use for measuring these little particles--when they bumped this nucleus, several things appeared in various directions. They had never noticed such a thing before and didn't understand what it really was. That was the birth of fission.

In 1939, as you will remember, all that Munich business and what not was going on; and, fortunately, these German scientists let the information slip out. A Jewish woman named Meitner and a man named Frisch mathematically reduced that experiment so they could explain it, and there it was. It was fission, or the enormous release of energy by this formula which Mr. Einstein brought out in 1905. That was the day that it became

To begin with, most people forget that they are only animals and that they have come down the old tree, Mr. Darwin's family tree, with monkeys hanging by their tails; that they have come down this tree in a succession of biological sports. I think that is the technical term. A sport is a variation that was not present in the parents and which cannot be found in the ancestral chain. Whether sports are produced by cosmic rays is a question which we will forget for the time being. We will just say that Darwin had produced a theory which seems to rationalize and explain these new forms of life that appear without inheriting characteristics of their ancestors. That means that our great-grandchildren of the forty-sixth generation may look very different from what we look like now. Doctors point to lots of things in our bodies that we do not use, which are inherited from our ancestors. We don't need all of them, and they are atrophying by degrees. Some functions are dropping out and new ones are coming in. So it is not at all beyond reason to assume that the funny pictures in popular magazines, that show a man from Mars or what not, may look like our great-grandchild of the ninety-sixth generation. I don't want to predict, but it is fun trying to. So we are going to have to recognize that you are only a half-developed specimen; that maybe you are not even half-developed. That term "half-baked" might have more meaning to it than we imagine.

Now, if you will assume that much, we will go to the next important point. Everything that we normally think--in those of us who do--is produced by impressions that register somewhere in our minds through our five senses. In other words, we think of things as hard, soft, transparent, opaque, red, green, blue, rough, smooth. All those things are merely terms that have come about through our personal experience. We bump into a concrete wall when you are running to catch a fly and we know the wall is hard. We also say it is solid. We also say the thing is static, that it is standing there waiting for us to run into it. I will prove in a minute that it is not any of those things. That is the easiest part of this lecture.

The point is that they appear that way to us. In other words, I am trying to make the point now--it is the most important one in today's talk--that we see the world only through our senses and that the world is not at all the way we see it. We are going to try to develop that in a moment.

If our senses were different, we would see the world differently. A common example is that in this audience statistically there should be some color-blind people. They might be partially color blind or totally color blind. Statistics would favor the "partially." But let us assume that we have a totally color-blind person here today. He thinks he is living a normal life, but it is not a normal life for a person who has color

Now, one of those things which is apparently irrational is light. Your picture of light probably is that it is a vibration that comes through interstellar space, or whatever it may be, transmitted through some mysterious mechanism called the ether. It has only a vibration, has no mass. It has no characteristics of solid matter. But all that is not true. We now know that light is no such thing. We thought that was what it was, because of our limited observations of it. Actually, light has a dual personality, a Dr. Jekyll and Mr. Hyde personality. It comes through space in this mysterious vibration like you get when you wave a clothes line. The wave goes on and on and yet the clothes line is still there. The ether would be the clothes line and the wave would be the light. So light is energy according to that method of approach.

In most of the engineering formulas you can use energy terms for light and explain its behavior. But along came the astronomers and picked up something that the energy concept wouldn't explain. That was that when we had an eclipse, the stars didn't appear where they should be in the heavens. They moved. Well, it was known that the stars didn't move; so what did move? It was the image that moved. In other words, the light did not come in a straight line. Now, if light was a true wave, it had to come in a straight line. But it didn't come in a straight line. Why did it not come in a straight line? It was moved by the gravitational effect of the moon or sun as the case may be. In other words, light had the properties of mass. It could be attracted, it could be pushed and pulled. You can't push or pull something that has no mass. So obviously light had another duality of character. It had the properties of mass. These facts are well known. They have been fully studied and understood, and the formulas for light now take into account its duality.

We human animals can't imagine a thing that has no substance at all one minute and the next minute behaves like a thing with substance. The reason is that our senses do not equip us to understand it. We don't have sensitive enough biological instruments to explain such behavior; so we say it is irrational. But mathematics makes it perfectly rational, and Einstein was the man who furnished the mathematics that translated mass into its behavior as energy. I am going to drop that one right there merely to leave you utterly confused.

I hope I have made one point that the world is not at all the way you see it. I am trying to get past this point so we can get over to things that you will be able to more nearly apply. But it is so important that I don't want to go further until you are reasonably convinced that what I have said so far is true.

Let us now explain what an atom can be made to look like and how it behaves. Take the simplest of all atoms, hydrogen. It happens that hydrogen on the periodic table of the elements has a mass of 1.008. That

This model of the atom is all pure bunk, gentlemen; but it is the kind of stuff that helps us to understand and visualize this atomic energy business. But you must remember that it isn't really so, because it isn't according to mathematics. Mathematics is the only thing that really explains it. You can see from this crude example why no human eye, with any kind of miscroscope known to man which has to use light, can ever see that atom. So the model was devised entirely by physicists who examined properties of the atom, recorded them mathematically and came up with that pattern. It is now agreed that this model is not true, but it is still so useful and explains so much about atomic physics that it is still being used. We are going to use it here, because if you understand it, you can understand a great deal about atomic physics. But please remember that this model is not really correct.

We have then the size of an atom of hydrogen. Now let us see what these things inside the atom are like. Boy, now we really go to work. The size of this electron out here is expressed by writing the three significant figures 1.88 and dividing them by 100 with 21 ciphers after it. That figure has been checked in laboratories all over the world--in Japan, France, England, Germany, and Russia--by physicists who never met each other, using different methods. The answer always comes up with the three significant figures that you see there. That, then, is the size of the electron. And it is in centimeters, by the way; not that it makes any difference. You can get a rough idea of how small that electron is in a thing as big as this atom. I said a minute ago that the atom is small, but it is big compared to the size of the electron.

As to this thing in the center, the nucleus, I am not going to give you the size; I am going to give you the mass. The nucleus has roughly 1800 times the mass of the electron. And remember that this is the simplest atom.

Now let us for a minute forget all these dimensions. Let us talk about the atom and see why it is so important to you gentlemen as military officers, as citizens, and as fathers of future generations.

To get a picture of the atom in your minds, let us imagine a parade ground out there on the campus and say that the parade ground is two miles wide. Let us assume that you hold in your left hand a baseball and in your right hand a green pea. You walk one mile to the center of that parade ground and drop the baseball. Then you keep right on walking another mile to the outer edge and drop the green pea. Now in very rough proportions an atom of hydrogen has a baseball in the center of a piece of ground two miles in diameter with a green pea on the outer edge going around like Hades. That is the kind of stuff the world is made of.

Just remember that that is the pattern of all the elements. As you go on up the scale, the next one is lithium. Lithium has seven jiggers in the center normally. It has three protons and four neutrons. In other words, each time you add a proton you get a new chemical element. Now, what Lord Rutherford did was this: he knocked a little proton out of one of these atoms and therefore got a new element or he added a proton and got a different element. When you were taught chemistry you were taught that these elements were indivisible, that they were the smallest things that can exist and retain their original properties. That is true. But you can change the original properties by changing the elements themselves. Rutherford was the man that discovered how to do it.

It is important to understand what an isotope is. Hydrogen, as you all know, occurs in two forms--heavy hydrogen and the ordinary kind. The difference is that in ordinary hydrogen you have only one proton in the nucleus, but in heavy hydrogen you have one proton and one neutron. The neutron, not having any electrical charge, doesn't change the character of the element. It is still hydrogen; but the neutron changes the mass, almost doubles it. So you have heavy hydrogen.

Water made out of heavy hydrogen is called heavy water. You remember, heavy water was what the Germans were trying to get by taking Norway, because Norway was the only source of heavy water. Heavy water is a very useful commodity if you are going to make an atomic power plant or bomb. It is a very good material to use for certain purposes. Its importance led to our bombing that famous plant in Norway--one of the most strategic missions that we had. The Germans tried to rebuild it again to get heavy water out of Norway into Germany for their atomic bomb experiments. That is the thing they were trying to get. Water made out of that kind of hydrogen is stronger than water made out of ordinary hydrogen.

Now, when you add neutrons to the center of this atom, this baseball or nucleus, you form isotopes. That is the meaning of the word "isotope." You run across it everywhere. It means that it is an element that is still the same chemically, but it has a different arrangement in the nucleus. It has more neutrons or less neutrons than some other isotope of the same element.

The interesting trait of isotopes is that, although it is possible to add another neutron to these nuclei, it is just like trying to pack too many mothers-in-law into one single frame house. The household usually gets very agitated. The result is that it gets radioactive; in other words, it is spitting out energy all the time. It is not a quiet, happy, peaceful household. Nobody puts on the carpet slippers, unfolds the newspaper, and sinks into a chair. Such a nucleus has an energy potential of a very high order. It is ready to go places and do things. And it does. This mother-in-law has worn out her welcome no sooner than she crosses the

I am always tempted to further confuse everybody, so I will write "neutrino." The neutrino is another thing that is necessary to explain the behavior of atoms. It has never been seen, but it can be calculated. It is mathematically necessary to prove how it works. No one has ever found one. There are any number of physicists looking in all kinds of funny areas to find the neutrino, because they are pretty sure that he is the black sheep of this whole family. They can't seem to uncover him from his hiding place. Nobody has yet found him.

I would like now to talk about energy for a moment. Let us come back to Einstein's formula, $E = MC^2$, because that has military significance of a very high order. These other things do, too, but they are a little more in the background.

Before we tackle this, let us try to look at the amphitheater in which we are sitting and see it with new eyes, not the eyes that are based upon normal wave lengths of light which can only see big objects, things a hundred-thousandth part of an inch in diameter, great big things like that. We are going to try to see this room in its true form.

By now your seats ought to be getting hard. You gentlemen in your seats are pretty confident that you are sitting on something that is not only very quiet, but pretty solid, and furthermore, something that is at rest. So you are not worried about the seats that you are sitting on. You should be worried in one sense, because they are neither quiet, nor solid, nor at rest.

If you now go back to the hydrogen atom and remember the parade ground and the baseball and the green pea, and remember that all other atoms are combinations that get more complex until you get clear up to uranium, you will begin to have a better understanding of these chairs. The uranium nucleus has either 238 or 235 particles, which means this family group in helium has become a clan in uranium, in which there are 92 protons, and either 143 or 146 neutrons depending on whether it is uranium 235 or 238, all living in one communal habitation in the center. That is a uranium particle. Now, you can imagine the kind of fights, bickering, and stress you get in a particle as complicated as that. That is why uranium is a good material for mass fission processes, because when you get as many people living under one roof as that, you are bound to have a few Communists and possible causes of trouble. At the same time, this uranium atom has 92 of those little electrons running around the outside.

Coming back to the chair, that is made up of elements reasonably familiar to you. Carbon is one very important one of them and oxygen is another. All these elements are built out of this kind of structure--great big holes

Now you know that this chair is definitely full of holes. You also know that it is transparent; it is not solid. Also it is constantly in motion, because the green peas in the chair, depending on the temperature after you have sat on it long enough, are going around in circles at varying speeds. For the moment we will say that they are going around at somewhere in the neighborhood of 10,000 miles per second. Well, when you stop to think that the fastest airplane that we talk about, one that is faster than sound, goes only one-fifth of a mile a second, you can realize that these electrons are really bumping along. And that is what you are sitting on. So that chair is not quiet; it is not solid; neither is it smooth, because how can a thing be smooth that is made out of these great big parade grounds with green peas all wiggling around? I hope I haven't shaken your faith in the world as you think you see it. Therefore when you talk of atomic physics, remember it is the other world you are talking about, not the one you see with your eyes or feel with your fingers.

Let's talk about where this atomic energy comes from. You are all familiar with what energy is, so I won't spend any time on that. But for all the years and years it has not been generally recognized that the energy you have been dealing with is in effect a form of chemical energy. It is secondhand energy, not primary energy at all. If you take coal out of the earth or pump oil or gas out and use them as fuel, or burn wood, or use water power, you are in each instance merely freeing the energy of those little electrons, which is chemical energy, or secondhand energy. All chemistry is based on the behavior of the electrons, not of these atomic nuclei. So all that man has played with and all the science that he has done until recently was based on this little electron out here, which is only one-eighteen hundredth of the size of this nucleus. When you put chemicals together and there is an explosion and the thing goes "boom," all you are doing is freeing the energy of these whirling green peas. You haven't touched this thing in the center, this nucleus, where the big amount of energy is stored.

Where do the green peas get all their energy? Why is it that through all the years they are the only things we have thought we could use, or that we have used, to get energy? This form of energy can occur as thermal energy, electrical energy, chemical energy, mechanical energy, and so on. All uses of energy that we have been making all these years have been simply changing one form of energy into another. When an engineer burned coal under a boiler, to make steam to push a piston or whirl a rotor, all he did was take energy in the fuel, these little electrons, put it through a series of processes by which it was converted into some dynamic form like a flowing stream of steam or gas or pressure in a cylinder. He released the chemical energy in the green peas and converted it into mechanical energy, then put the mechanical energy to work. All he was doing was harnessing these green peas.

So there is the formula $E = MC^2$. I have told you how the atom behaves. The thing I haven't told you is how this energy comes out of the atom and how it is we never discovered it until recently. I have explained that the first contact with this business was Madame Curie's isolation of radium and study of its behavior. The actual unlocking of the secret never occured until that famous year 1938, when Hahn and Strassmann bumped the nucleus of an atom with a projectile and the nucleus split and formed a family of different parts. I did write on the board for you in the early part of this discussion that the weight of the hydrogen nucleus is 1.008 and of the helium nucleus 4.003 and I said that if you could combine four atoms of hydrogen, you would come out with .029 missing. That missing weight is what would disappear if you could combine these four atoms. That would come out as energy under the Einstein formula. It doesn't look very big to you, but if you now translate it into this enormous figure and multiply it out, you would see that the amount of energy you would release would be tremendous. If you could perform that atomic reaction of changing four units of hydrogen into one of helium, you would get that amount of energy (pointing) released through the minute difference in weight that results.

That is the reaction that occurs all the time in the sun. All along through countless years we have had atomic reaction going on in front of our eyes and have not known it. Everything that comes to the earth from the sun comes from that very reaction. The sun supports the earth. The earth is a satellite. Alone it is a dead body. It gets its life from the sun.

Everyone has wondered how the sun keeps on shining, why it constantly burns itself up but never burns itself out. Let us look at some figures that have to do with the sun. It has been calculated that the sun releases as energy and consumes under the Einstein formula, which we wrote a minute ago--$E = MC^2$--400,000 tons of its hydrogen per second. Every second the sun uses up 400,000 tons of hydrogen. But remember, the sun is a large body. By figures of this kind worked backward the physicist can determine the expected life of the sun. It is on such figures that the predictions of Sir Arthur Eddington about genes are made. And that is the reason why the sun has shone for two billion years and is still a very active energy-giving-out body.

Now let us draw a large circle and imagine that it is the sun, and a small circle and imagine that it is the earth. The sun is radiating energy in all directions. You see that the earth can intercept and capture only a minute fraction of the energy of those 400,000 tons a second of hydrogen. What we do capture--and I am quoting these figures--is 30 pounds per second. I used that figure in a lecture a while ago and someone commented that it should be four pounds. I took this from an authoritative source, while the other was stated merely by a gentleman who attended the lecture. So I am going to stick to 30 pounds because it is bigger and

Now, chlorophyll in that state can perform chemical operations which could not be performed by normal chemicals, and that in effect is how plants grow. Plants pick up inert matters in the soil, in fertilizer, and in the atmosphere of the air, like carbon dioxide, and so forth; and by means of the sunlight energizing this material called chlorophyll, the chemical process becomes so activated that it can take these inert materials that man cannot join together and can put them together, link them right together, by the energy of these electrical orbits. When it does that, it creates living matter. This living matter is one of those amino acid bases for protein on which man and every animal live, on which we can all have grandchildren and great-grandchildren. Without that simple process of harnessing the radioactivity of the sun, we would not be here; nor would we capture much of the sun's energy. It is captured by this peculiar mechanism.

That is the process called radiation synthesis, which means that by radiation you can synthesize complex materials not otherwise possible by chemistry or any other normal method known to science. If you want to extend your reasoning, you can ask yourselves this question: "Will man ever be able to take the radioactivity that he is now learning how to unharness from physically inert materials of the earth and join together chemicals into living matter? In other words, can man be a creator?" Now you can begin to see why atomic energy is not merely a bomb, why atomic energy is not merely building power plants. Atomic energy is a new way of life. It is not a question of curing cancer, or of radioactive tracers to explore the course of diseases in the body or the metabolism in human beings. It is a new understanding of the life processes. If man can harness them, his whole life will be changed on this planet. Our children may be utterly unlike us. Now we say that we really are what we are by some peculiarity of inheritance. But, as I have mentioned before, we have been able by X-rays to change the sex of fruit flies in the laboratory, the X-ray being nothing more or less than a wave of radioactive energy.

Now you begin to see a whole new pattern of science in its true light, instead of as it was taught in my day. In physics in my day you started out by studying light. Then you turned over that chapter and studied sound, turned that over and studied mechanics, then electricity, then magnetism. But that can be no more. All of these so-called separate branches of science respond to the same laws and fundamentals. Now they can all be studied in one general chapter because of their interrelation. X-rays no longer are taught as being peculiarly different from light, peculiarly different from radio waves, peculiarly different from radioactivity. All are sisters under the skin; all are based on the same principle. So atomic science has far more long-reaching, significant aspects than the simple one of energy.

and there it is just like an unwanted relative coming into a household. The minute it gets in there, things begin to happen. The proportionate forces that hold this nucleus together are distorted.

The nearest you can picture it is this: It starts out as a round nucleus. After it absorbs this little particle, that round nucleus begins to vibrate. It begins to constrict at the center, to vibrate in and out, like an elastic band. All of a sudden this goes too far, the opposite edges come together in the middle, and the nucleus snaps in two. These two halves of the nucleus, being then separate, exert the repulsive force of their positive charges of electricity, because each half has one less proton in it and all protons are positive. So these two positive fragments, like two positive poles of a magnet, resist each other and fly outward at tremendous speeds. As they do that, they kick overboard the unwanted left-over neutron. So out of this union come these little particles, neutrons unwanted by either of these family groups.

Now, you can see that if more than one neutron flies out each time a nucleus is hit, each neutron as it flies out can hit another nucleus and cause another fission. That is the way a chain reaction is produced. So you can understand the explanational equation basis of atomic energy. In other words, you can start with just a few neutrons speeding around. If they don't hit targets and multiply the fissions, they are just going to speed around as ordinary atomic energy in the form of radiation from radium or pitchblende ore. But if you have a critical mass of this material, which is another way of saying if you have enough mass that when these neutrons speed out from one nucleus fission they have to hit another target, they can't go through the mass out into the atmosphere and be lost. If you don't have this critical mass, your reaction could have as many neutrons lost to the outside atmosphere as those that are generated through fission, and you would never get anywhere. But the minute you have this critical mass, they don't get lost. They stay right in the mass and keep splitting nuclei, which in turn generate more neutrons by that explanational curve, and in this incalculably short time, this fraction of a second, the splitting has proceeded to such an enormous degree that the whole mass is in explosion and is freeing energy.

The energy comes in part from the speed with which these particles come out and in part from the fact that when this neutron comes along and splits a nucleus of uranium, two different particles come out as a result of the fission. Lanthanum is one and crypton, one of the noble gases, is the other; or you might get barium. These little particles that go out, which are new family groups, traveling with great speed, are called fission fragments. Most of them are highly radioactive, with a degree of radioactivity that may be called thousands of times that of radium. You know you can't go near pure radium, because it destroys human tissue. So these fission

COLONEL McKENZIE: Mr. Ward, I think we of the Industrial College are well aware of the reasons why your board of directors has elevated you from president to chairman of the board since your last appearance here. On behalf of the Commandant and the faculty and students of the Industrial College, I want to thank you for giving us a lecture which in your own terms has brought the science of atomic energy down to language that we can understand. I am sure we will never forget it.

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