A UNIT ON ATOMIC ENERGY FOR INCLUSION
IN EXISTING HIGH SCHOOL COURSES

by

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CHAPTER I

INTRODUCTION

General Considerations

In the early part of the year 1945, the United States was still engaged in the war with Japan. High school pupils were most interested in calls from the selective service. Teachers of chemistry, physics, and other science courses were constantly being questioned about high explosives, poisonous gases, jet propulsion, aerial warfare, bombs, rockets, and the mechanics of modern war. The press told of the battles fought, the heroes made, and the long casualty lists resulting from the war. Most of the popular magazines were filled with articles on the modern tools and methods of warfare.

Then suddenly a blinding flash, a towering column of smoke and dust, and much of this was changed. The first atomic bomb had been dropped on Hiroshima. A few days later the second atomic bomb was released over Nagasaki, and in a few days the war was over.

This abrupt change in the method of mass destruction was followed by a like change in the contents of the popular press. Editors who had little or no knowledge of
atomic structure or nuclear physics were suddenly called upon to explain one of the most technical problems of modern times. The men who had actually built the bomb were not available for comments at that time. The editors, therefore, turned to the nearest persons who had studied science for an explanation, with the result that a great deal of confusion ensued. Claims and counterclaims were made. One authority was of the opinion that atomic bombs would split the earth. Another said that the regions where the bombs had been dropped would not be suitable for human habitation for a thousand years. Fantastic claims and actual facts became so confused that one did not know what to believe.

This great change in the reading habits of the American people is illustrated by a study of the "Reader's Guide to Periodical Literature." In the ten years from 1935 through 1944, there were listed only 174 articles that were concerned with the atom or atomic power, and most of these were about Lawrence's cyclotron, Van de Graaff's generator, and other spectacular machines that excited the imagination of the readers. As a result of the war, only nine such articles were listed in 1942, six in 1943, and five in 1944. The bomb having been dropped and the war having ended, the latter half of 1945 alone found 311 articles appearing under the heading "Atom."
By 1946, this heading had been broken down into a number of subtopics, but there were still 236 items listed under "The Atom."

In studying these figures, one should remember that they do not include the many articles that appeared in the technical journals, but rather those appearing in magazines available to the general public, especially to high school pupils through their school libraries. Likewise, the many thousands of items to be found in the newspapers were not included. The students read and discussed many of these articles with their strange mixture of fact and fiction until they became thoroughly confused.

It is this feeling of uncertainty on the part of the pupils that has formed the basis for the following study, for as Noyes points out, "-- it is the student generation of today that must develop its life within the framework of the atomic age." (50:344)

He goes on to say,

In the present situation it appears to me that we science teachers, and especially teachers of physics and chemistry, have a golden opportunity and a special duty to arouse the interest of our students in some of the many problems arising from the development of the atomic bomb. The general nature and theory of the bomb itself is a fascinating subject that should be discussed in any course in general physics, ---

A unit of work such as the following is, therefore, a necessary part of any high school chemistry or physics
course, but the authors of the newer textbooks have either neglected the subject entirely, or have presented only very meager information on atomic energy. This paper is written to aid the students and teachers in becoming more familiar with the true nature of atomic energy and to give them some basis for judging current literature on the subject. Reference material for teachers is also included.

In presenting a unit of work on atomic energy to high school pupils, it is necessary to speak in terms that can be understood by pupils having a wide range of ability. There is always the danger, therefore, that some of the pupils will misinterpret the facts and assume that they can learn all about atomic energy in two or three weeks. It should be pointed out to all of the pupils that the work covered in the unit is only a very brief outline of a very intricate subject. The unit does not and cannot answer all of the questions that will arise during a discussion of atomic energy in the classroom, but it should arouse the interest of the more talented students, and guide them to a further study of nuclear physics.

Where to Include the Unit

The study of atomic energy could best be included as a unit of work in the latter part of the high school physics or chemistry course. It could well be an
expansion of the unit on the radioactive elements that is included at present in most physics and chemistry textbooks. This opinion is justified on the basis that much of the work of the radioactive elements is rapidly being replaced by artificially produced radioactive materials that are more effective than the natural ones and by x-ray machines. Furthermore, there is very little reference to the natural radioactive elements in the current literature, and most of the pupils have no interest in them as radioactive elements. For example, uranium is an element with which most of the pupils are somewhat familiar from reading the popular magazines, but few of them regard it as a radioactive element. Instead, it is to them the "stuff" from which atomic bombs are made.

Material Presented

It is assumed that high school pupils who are completing a course in chemistry or physics will be familiar with the general structure of the atom. Enough material on this subject is included to refresh their memory, and references are listed for those who need further study on atomic structure. A more detailed discussion of the atomic nucleus is presented, and the subject of isotopes is introduced.

A very brief study of the radioactive elements is
presented to indicate one method of the release of nuclear energy in nature. The alpha, beta, and gamma rays are defined, and their importance in atomic transformations is illustrated. The artificial production of radioactive isotopes is introduced to the pupils, and discussed to some extent.

Also included is a section concerned with the machines and instruments used to study the atom. While these devices have not resulted directly in the release of large quantities of atomic energy by fission, they have played an important part in the development and study of atomic energy. An understanding of these machines is essential to any modern study of the atom.

The mass-energy concept is introduced. Einstein's equation for the equivalence of mass and energy is discussed briefly, and the conversion of hydrogen to helium in the sun is used to illustrate the validity of the equation. Other illustrations are also given to show that mass may be converted to energy or energy may be made to appear as mass.

The chain reaction and atomic fission are studied as possible sources of useful energy. The bombardment of uranium with neutrons is explained, and the correlation between the amount of material that is used up in the reaction and the energy that is produced is pointed out. A
comparison is made between the energy released by atomic fission and the energy of a chemical reaction.

The separation of the isotopes of uranium was an important step in the controlled release of atomic energy. A discussion of the chief methods used to accomplish this separation is, therefore, presented, and the difficulties that were encountered in developing these processes are illustrated.

The operation of the atomic pile is explained in simple terms along with the need for shielding and other problems that arose in the development of the pile. The pile is discussed not only as a source of plutonium but also as a possible means of generating heat and electricity. The limitations in the use of the pile are shown, and the applications of the by-products in medicine and industrial research are illustrated.

A section on the possible construction and the use of atomic bombs in warfare is presented. The results of the atomic bomb tests are interpreted and the possible strategy of atomic warfare is briefly explained. Only enough of this material is included to make the pupil aware of the need for the control of atomic energy. The unit does not describe in detail the different plans for atomic control, but it does introduce the Baruch plan as being the one most likely to be effective of those proposed thus far.
Since most of the pupils who register for a course in chemistry or physics in high school have no vocational ambitions in these fields, it is felt that the materials presented should be understandable rather than highly mathematical. Wherever possible, the theory behind the development has been treated lightly, and the detailed study of these theories left to the more intelligent students and the teacher.

From a survey of current literature on the subject, it was found that there were several false and pernicious ideas about atomic energy and the atomic bomb. The false opinion that was expressed most often was that the United States alone has the 'secret' of atomic energy. Material is included in the study that makes it clear that there are no secrets about the scientific facts, and only a few secrets about the apparatus, techniques, and industrial methods used in the development of the atomic bomb. Another false belief is that the United States is the only nation with the technical ability, raw materials, and industrial strength to develop atomic energy. Other equally pernicious beliefs are that some defense will soon be found against atomic warfare and that the bomb is not as destructive as the scientists would have one believe. As much material is included in the report as is needed to show the fallacy of each of these erroneous ideas without
making the report morbid.

Usefulness to the high school pupil also served to determine the materials included. A survey of the popular press and newspapers indicated that many of the articles assumed a previous knowledge of the reader of such things as the atomic pile, isotopes, radioactivity, radioactive poisons, and other points concerned with the development of atomic energy. For example, many of the articles on legislative measures for atomic energy control also assume that the reader has such a background. These articles are not easily understood by people who lack this foundation.

Other topics that deserve to be included have value mainly as general information; for example, the Wilson cloud chamber and the Van de Graaff generator are of considerable scientific interest and add to the continuity of the story of the development of atomic energy even though they are not directly concerned with its release.

An annotated bibliography of books and magazine articles that will be of use to both the student and teacher is included. Most of these articles have appeared in ten of the magazines usually found in high school and public libraries, and the books have been selected because of the simple fashion in which they present the various phases of the study of atomic energy. Care should be exercised in the use of the articles listed here because some of the
more fantastic items have been included to aid the pupil in developing discrimination as to what to believe.
CHAPTER II

THE DEVELOPMENT OF ATOMIC ENERGY

The Composition of Matter

All of the material of which the earth is composed is made up of the ninety-two stable elements. These basic elements, such as lead, copper, or mercury, cannot be broken down into other substances by chemical means. Any material that can be decomposed by chemical means is a compound consisting of molecules, and is made up of atoms of two or more elements. Of these elements, hydrogen is the lightest, and uranium is the heaviest.

The individual atoms of an element are exceedingly small, so small, in fact, that it is difficult to imagine their size. Some approximate idea of the size of an atom can be obtained as follows. By measuring the radius of a soap bubble, the area of its surface can be calculated. After bursting the bubble, its weight is accurately determined, and from these data, the thickness of the film that formed the bubble is calculated. From such data, it has been determined that the films of soap bubbles are sometimes less than one-millionth of a centimeter thick. Since the bubble must consist of at least one layer of soap molecules, these molecules must have a diameter

...
smaller than one-millionth of a centimeter. Each soap molecule is made up of several atoms, therefore, the atoms are even smaller than one-millionth of a centimeter in diameter. (46:136)

Since the atoms are so very small, their weights are also minute. Any weighable amount of an element must contain a large number of atoms. One gram atomic weight of any element contains a number of atoms that can be represented by a six followed by twenty-three zeros, or as it is more often written, \(6 \times 10^{23}\). For hydrogen, the lightest of the elements, this vast number of atoms could be placed in a cubic box slightly smaller than nine inches on a side. It is also estimated that a single gram of gold, a speck of material slightly larger than the head of a pin, contains a number of atoms that is represented by a three followed by twenty-one zeros \((3 \times 10^{21})\). This is about three thousand billion billion atoms in a single gram of material. (46:137)

Atoms in turn can be divided into electrically charged particles. These positive and negative particles must play an important role in the structure of the atom. On the other hand, ordinary matter is nonelectric, and likewise atoms normally have no electric charge. These conditions are possible only if the atoms contain equal numbers of positively and negatively charged particles.
In explaining the composition of the atom, an understanding of electric charge is therefore necessary. There is a basic unit of electric charge that can never be decreased. It is an indivisible unit, and any electric charge is a whole multiple of it. This unit may exist as either a positive or negative charge. If it is positive, the charge cannot exist with a smaller mass than the mass of the lightest element, hydrogen (except in a very special case, the positron). This positive unit of charge is called the proton. When the mass is negative, the smallest unit occurring has only one eighteen-hundredth of the mass of an atom of hydrogen. The negatively charged unit is called an electron and has a radius about fifty thousand times smaller than the radius of the hydrogen atom.

The atom itself is not only small and light, it is also nearly empty. In its center there is a tiny, heavy particle that has a positive charge. This particle, the atomic nucleus, is about ten thousand times smaller than the atom, but in it is concentrated almost the entire mass of the atom. Around the nucleus move as many negative electrons as the nucleus contains positive charges. From these facts it can be seen that only a small portion, actually only about one-million millionth, of the total volume of the atom is occupied by the nucleus and the surrounding electrons. The rest of the atom is empty.
As an illustration, one may consider an atom of the element uranium. This is the heaviest of the naturally occurring elements, therefore, its atoms would be the heaviest of the atoms that occur in nature. If one of these atoms were enlarged a thousand million times, it would be about a foot in diameter. If its weight were increased in the same proportion as its volume, the atom would weigh about a thousand pounds. In its center, there would be a kernel about the size of a grain of sand. This is the nucleus. The part of the atom outside the nucleus consists of electrons. In the case of uranium, there are ninety-two and, on the scale of magnification used, the total weight of the electrons would be about a quarter of a pound. All of the rest of the thousand-pound mass would be in the nucleus. In other words, the magnified kernel, about the size of a small grain of sand, would weigh over nine hundred and ninety-two pounds. A thimble full of uranium nuclei would weigh thousands of tons. (34:65)

Atoms differ from each other in the number of electrons surrounding the nucleus and in the equal number of protons within the nucleus. The number of positive unit charges in the nucleus is equal to the number that denotes the position of the element in the periodic table and is called the element’s atomic number, for example, the
lightest element, hydrogen, occupies first place in the table and is composed of a single positive charge with one electron circling about it. Helium, in second place, has a nucleus with a positive charge of two and two electrons moving around it. In the same way, each of the nuclei of the elements has a positive charge that is one unit greater than the central charge of the preceding element, and surrounding electrons equal in number to the number of charges on the nucleus.

If the nuclei of the atoms were built only of protons, the weight of the atoms would be equal to the number of protons they contained. Actually, in most cases, the atomic weights are much larger; for example, an atom of oxygen, with the atomic number eight, has eight protons, and its atomic weight is sixteen. This would indicate that in addition to protons, the nuclei of most atoms must also contain other elementary particles. These would contribute to the weight of the atom, but would not alter the electric charge. These particles, being electrically neutral, are called neutrons. The mass of the neutron has proved to be almost exactly equal to the mass of the hydrogen atom. The number of neutrons present in the nucleus is, therefore, equal to the difference between the atomic weight of the element and the number of protons it contains as indicated by its place in the periodic table.
Since the oxygen atom has an atomic weight of sixteen and an atomic number eight, it would have eight neutrons in its nucleus.

The chemical properties of an element are determined by the number of electrons that revolve around the nucleus. The electrons determine the compounds that the elements can form and the physical and chemical nature of all substance. In particular, the number of electrons in a neutral atom determines what element it is, but not all atoms of a given element are all alike. They may differ in atomic weight, but not in atomic number. This difference in atomic weight is explained by the presence of different numbers of neutrons in the nucleus. Such nuclei are called isotopes. From the fact that only a few isotopes for each element exist in nature, it is evident that the ratio of protons to neutrons cannot be changed arbitrarily. In all of the ninety-two elements, there are two hundred ninety stable isotopes, which is also the number of different kinds of atoms that occur in nature. Two substances whose isotopes are very important are hydrogen and uranium. The atomic weights of the isotopes of hydrogen are approximately 1 and 2, and those of uranium are 234, 235, and 238. The isotope of hydrogen having the atomic weight of about 1 is the common form of the element. It consists of a single proton and an electron. For the
isotope of atomic weight 2, the nucleus contains a proton and a neutron with a single electron revolving about the nucleus.

It is believed that the protons, neutrons, and electrons are the ultimate units of all matter. The atom, then, is not an elemental particle, but a complex structure, and, as such, is subject to further division. (34: 15)

Nuclear Transformations

The amount of energy stored in the nucleus of the atom is millions of times greater than that obtained by known chemical processes. Chemical reactions affect only the electrons in the outer shell of the atom. When two atoms of hydrogen combine with one atom of oxygen to form a molecule of water, the nuclei of the atoms remain unchanged. Only the arrangement of the outside electrons is changed. All efforts to alter the composition of the nucleus by chemical or ordinary physical means have been useless.

The transformation of one element into another requires a change in the atomic nucleus. In atoms of the greatest atomic weight, such as radium and uranium, a condition of limited stability exists. The elements of this group break down spontaneously, giving rise to the
phenomena known as radioactivity, that is, with the property of emitting rays. It has been demonstrated that these rays are of three kinds which are designated by the first three letters of the Greek alphabet; alpha, beta, and gamma. Further research has demonstrated that only the gamma radiations are true rays similar to x-rays. The alpha and beta rays were shown to be particles of matter flying out of the nuclei of radioactive elements at terrific speeds, giving them some of the characteristics of rays. (46: 137)

The alpha particles are identical with the nucleus of the helium atom; that is, they are composed of two protons and two neutrons, which would give them a double positive charge. Since the nucleus of the original element is also composed of protons and neutrons, it is assumed that two of each unite to form the alpha particle. Enough energy is released when this particle breaks away from the radioactive element to give it the speed necessary to appear as a ray. Later, this particle loses its speed, picks up two electrons from the surrounding air, and becomes a helium atom.

Beta particles have been demonstrated to be high speed electrons. These electrons are ejected from the nucleus of the atom, but the nucleus was described previously as being made up only of protons and neutrons. The ejection
of electrons from such a nucleus is explained by the theory that during the energy change that takes place in the nucleus of a radioactive atom, it is possible for a neutron to be converted into a proton. When a neutron is changed to a proton, an electron is created and thrown out from the nucleus with a speed nearly equal to that of light.

Since particles have been ejected from the nucleus in this process, it is evident that a different element must be formed. If an atom emits an alpha particle, the atom becomes an element with an atomic number lower by two and an atomic weight lower by four than the original element. The emission of a beta particle leaves the mass of the atom unchanged, but increases the atomic number by one. In some cases, gamma rays are also given off with these particles, but affect neither the atomic weight nor the position of the element in the atomic table. Often the nucleus that remains is also unstable and undergoes further disintegration.

As a specific example, consider radium which has an atomic number 88 and an atomic weight 226. This metal releases an alpha particle to become the gas, radon, with the atomic number 86 and having a weight of 222. Radon is also radioactive, and emits another alpha particle to become an isotope of polonium which in turn ejects still
another alpha particle to become a radioactive isotope of lead with the atomic number 82 and the atomic weight 214. Instead of ejecting an alpha particle, this element emits a beta particle to become an isotope of element 83, bismuth, having the atomic weight 214. The final product of the disintegration of any of the naturally occurring radioactive elements is a stable isotope of lead.

The amount of energy released in this process is now accurately known. When one gram of radium is transformed entirely into lead, the energy present in the emitted particles would be sufficient to raise twenty-five tons of water to the boiling point. This process is so slow that it would require thousands of years to take place, and no method is known that will change the rate of this transformation. (46:142)

The problem of the artificial disintegration of the nucleus was first solved by bombarding nitrogen gas with alpha particles from a radium product. Occasionally a collision occurred, about once in a million times, between the alpha particles and the nitrogen nuclei. Whenever this happens, the two nuclei inter-react, just as two clashing atoms react chemically and form chemical compounds. In this case, the alpha particle combines with the nitrogen nucleus which has a positive charge of 7, and a proton is released. This proton is ejected from the
atom, and the charge of the nucleus that remains becomes 8. A nucleus with a charge of 8 is an oxygen nucleus.

The oxygen produced from nitrogen is a stable isotope of ordinary oxygen, but in the case of some nuclear reactions, radioactive nuclei may be formed which change to more stable elements by the emission of rays. For example, when aluminum is subjected to the action of alpha particles, an aluminum nucleus is occasionally hit directly. It captures the alpha particle, at the same time splitting off a neutron which is ejected. Since the alpha particle has 2 protons and the aluminum nucleus contains 13 protons, the resulting nucleus has a positive charge of 15. Element 15 in the atomic table is phosphorus.

This phosphorus differs from the ordinary element in having fewer neutrons in the nucleus. It is a radioactive isotope of phosphorus which changes to silicon by a peculiar process. One of the protons in the nucleus changes to a neutron, and a positive electron is ejected. This positive electron, called a positron, appears only during atomic disintegration. It has a mass equal to the mass of the regular electron and an electric charge exactly equal to the charge of an electron, except that the charge is of the opposite sign. The positron combines with an electron, and both disappear, their mass being transformed into energy.
Tools for Studying the Atom

Since atomic nuclei are built of protons and neutrons, it was reasonable to believe that the nuclei would react with these particles if they could be brought close enough together. Also there was the possibility that alpha particles traveling at higher speeds might produce transformations with the heavier elements. The first of these particles to be used was the proton. It was given a high velocity by falling through a difference of potential provided by a series of transformers. This experiment opened the way for the invention of a series of machines known as "atom smashers." With these instruments, particles could be speeded up almost to the velocity of light, and the real conquest of the atom was underway.

One of these machines, the Van de Graaff generator, operates on a simple principle. If a glass rod is rubbed with silk, an exchange of electrons takes places between the glass rod and the silk. As a result, the glass rod will have a positive electrical charge on its surface, while the silk has a negative charge. Similarly, an electric charge can be placed on a moving belt of silk or paper. Since neither will conduct a current, it is possible to drain off this charge by passing the belt over a collector made of fine wire points. The electric charge
The Working Principle
of the Van de Graaff Generator

Positive charges are sprayed on the moving belt at 'A' and are removed by a conductor at 'B'. They travel to the outer surface of the sphere where huge charges can be stored.

(54;283)

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can then be conducted through wires to a suitable storage place where large charges may be held.

The machine itself consists of a large metallic sphere mounted on the top of an insulating column. Instead of relying upon friction to produce the electric charge, transformers capable of producing as high as 20,000 volts are used. This charge is sprayed on to a silk belt that passes up through the center of the insulating column and is removed at the top by a wire brush. The charge then travels through wires to the outer surface of the metal
sphere. Even relatively small generators having spheres two feet in diameter have produced potentials of 1,500,000 volts, while larger spheres of polished aluminum fifteen feet in diameter have served to accumulate potentials of as much as seven million volts.

If no other provision is made for discharging the metal globes, huge sparks may jump as far as forty feet from them. In atom smashing, the electrical discharge is not permitted to dissipate itself as sparks in the air. Instead, it is discharged through large vacuum tubes to speed up ions which are then focused on a small target that contains the atoms that are to be studied. (54:282-283)

The operation of the cyclotron is based on the theory that makes use of resonance, a principle whereby an ion can be set in motion by small pushes and pulls applied to it in the proper rhythm. The whole process of acceleration is carried out in a strong magnetic field which tends to make the ions travel in circles. The most conspicuous part of the cyclotron is the electromagnet which generally weighs thousands of pounds. It is constructed with the pole faces only a few inches apart, making the magnetic field between the poles very intense. One of the important considerations in the operation of the machine is for the magnetic field to remain uniform and constant.
A flat circular tank of non-magnetic material is designed to fit between the poles of the magnet. Within this tank are two hollow metallic "Dees," so called because they resemble the capital letter "D." Their shape can best be described by saying that together they form the two halves of a flat pillbox that has been sawed along its diameter. The dees are supported by insulators and are connected to a source of electric current in such a way that a difference of potential of several thousand volts may be applied between them. A source of ions is located at the center of the dees, and the whole tank is evacuated.

The Dees of a Cyclotron

These dees would be enclosed in an evacuated tank and placed between the poles of a huge magnet. A charged particle starting at the center is alternately attracted by section 'A' and 'B'. It travels in a spiral picking up speed each time it crosses the space between the dees. It finally leaves the machine through a thin foil window at 'C' and strikes the target.
When the current is turned on in both the electromagnet and the dees, an ion starting from the source at the center is accelerated by the difference in potential between the dees. As the ion enters one of the dees, the magnetic field bends the path of the ion into a circle, and it heads toward the other dee. Again in traveling across the space between the dees, the ion is accelerated. By proper adjustment of the transmitter that controls the high frequency potential, it is possible to change the charge on the dees at the exact moment when the ion crosses the boundary line between them. The ion is speeded up each time it crosses the space between the dees. Since a rapidly moving particle is deflected less by an outside force than a slowly moving one, the ion would assume a spiral path as it picks up speed in the magnetic field. Particles are produced whose velocities are in excess of 25,000 miles per second.

When these high speed particles reach the edge of the dees, they may be focused upon a target composed of the material to be studied. Another possibility is to provide a slit in one of the dees through which some of the ions can escape. They are then guided to equipment in a more suitable location for observation. (29:131-134)

Another of the new machines for the acceleration of particles is the betatron. Its main part is also a large
electromagnet, but it accelerates electrons, not ions. The process depends upon the fact that the magnetic field used is not constant, the coils of the magnet being fed by alternating current. It accelerates electrons to very high speeds, but the results are new, and their bearing on the atomic nuclei is still uncertain. (64:92)

One of the simplest instruments used in the study of the atomic particles is the Wilson cloud chamber. This is a device that makes visible the paths taken by the charged particles that occur when atoms disintegrate. As was mentioned before, these tiny particles are traveling at terrific speeds. In their journey through the air, they break up or ionize every particle which they encounter, and their path is littered with damaged molecules and atoms. This break-up usually consists of knocking a few of the outer electrons lose from the atoms and leaving them as charged particles. The path that appears in the cloud chamber is caused by these particles.

A simple form of this device consists of a glass bowl with a glass plate waxed on for a lid. Enough water is added to the bowl to fill it about two-thirds full, the rest of the bowl containing moist air. Some provision is made for expanding the air in the bowl suddenly, causing it to cool slightly. Cool air will not hold as much moisture as warm air; therefore, tiny droplets of water
form around any dust particles that may be present in the bowl. Ionized particles will also cause droplets to form in supersaturated air, but if neither dust nor ions are present, the air in the chamber remains in a supersaturated state. A piece of a disintegrating atom, such as an alpha particle, crashing through this supersaturated air leaves a trail of ions behind, which then appear as a streak of water droplets. Since these streaks last for only a fraction of a second, cloud chambers are usually equipped with cameras to take pictures of the paths left by the invisible particles streaming through the chamber. (29:132-135)

When it is not especially desired to see the path left by the charged particles, another instrument called the Geiger counter is used. This is the most sensitive instrument ever invented for the detection of ionized particles. In its simplest form, the Geiger counter tube consists of a glass envelope enclosing a tiny central wire that is surrounded by a metal cylinder. Before the glass tube is sealed off, a gas, such as argon, is introduced at low pressure. Provision is made for connecting the metal cylinder to the negative terminal of a battery and the central wire across a suitable resistance to the positive terminal. When a ray from a radioactive source passes through the tube, it ionizes the gas, giving rise to both
The Geiger Counter

(1) The counter counts an atomic particle by recording a shower of electrons knocked out of gas atoms as the particle passes through the tube. (3:103)

(2) Electrons spread along the wire and multiply themselves by knocking electrons out of other atoms. The particle passes out of the tube. (3:103)

(3) An electrical impulse is sent out of the tube on the wire, indicating the passage of one particle. (3:103)

(4) It travels through an amplifier that in turn operates a mechanical counter. (A) Amplifier (B) Battery (C) Counter (R) Resistance (15;55)

positive and negative ions as well as electrons. Through a multiplication process brought about by collisions between electrons and the gas molecules and the release of electrons from the metal cylinder, a large surge of ions is built up. Electrons collect on the wire unit until a
definite charge is present, which then, through the use of a suitable amplifier, trips a mechanical counter to record the passing of the charged particle. The wire is then discharged through a ground connection, and returns to its normal condition to await the next charged particle.

When a great deal of radioactivity is present, it is often desirable to record several rays at a time rather than the passage of a single particle. This can be accomplished by a simple adjustment that holds the electrons on the central wire until a greater charge has accumulated. Counters have also been built that will measure the total amount of radioactivity in the air at any given moment. In the development of the atomic bomb, these counters were used to warn the workmen of the presence of deadly rays.

The Equivalence of Mass and Energy

In 1905 Einstein proposed his now famous equation, \( E = MC^2 \), which shows the equivalence between the energy, \( E \), of any substance and its mass, \( M \). \( C \) in the equation represents the velocity of light which is the enormous quantity of 186,000 miles or 30 billion centimeters per second. Since this quantity is squared in the equation, the figure to use is \( 9 \times 10^{20} \) centimeter squared per second squared. The equation means that if a piece of
matter is transformed completely into energy, it ceases to exist as matter and appears as energy, usually in the form of heat. Mass is one particular form of energy that can be converted into other forms of energy such as heat or electrical energy.

The reverse is also true. When the energy of a body is increased by raising its temperature or increasing its speed, the mass of the body becomes greater. The reason that this increase in mass cannot usually be detected is that mass represents a great reservoir of energy. Small additions to this pool of energy are not easily observed. The kinetic energy of even the fastest bullet increases the mass of the bullet less than a billionth part of the original weight, but changes in the mass of particles as small as the atom or electron are easily detected. For example, in speeding up a proton in the cyclotron, its mass will increase and this added weight must be taken into consideration in the operation of these machines.

The mass-energy process works both ways, but in nuclear reactions the important feature is the release of energy as the mass of the atom is used up. In the atomic nucleus, some of the mass of the particles of which it is composed has disappeared, and the binding energy that holds the nucleus together makes up for the loss in weight. In other words, the mass of the atomic nucleus
is always somewhat smaller than the sum of the masses of the protons and neutrons forming it. This difference in mass, or mass defect, is the direct consequence of the binding energy that holds the protons and neutrons together. To separate them it is necessary to do work equivalent to the amount of mass lost in building up the nucleus. (32:7-9)

The mass-energy concept has been confirmed by numerous experiments. To illustrate, consider the three lightest elements, hydrogen, helium, and lithium. The particular isotopes to be observed are the most abundant ones; namely, hydrogen of mass about 1, lithium of mass about 7, and helium with a mass of about 4. Experimentally it is possible to shoot a helium nucleus into the lithium nucleus and produce two helium atoms. This is an actual transmutation of the elements. The masses check roughly: 1 for hydrogen plus 7 for lithium gives 8 for two helium atoms each having four units of weight, but if the true masses, which are known accurately to one part in 100,000, are used, a difference in the weights is observed. From chemical tables, the hydrogen mass is found to be 1.008 and the lithium is 7.018, which adds up to 8.026, but twice the mass of the helium atom, whose weight is 4.004, is only 8.008. The product falls short by 0.018 of a mass unit. This loss in mass is made up by the
appearance of energy. In this experiment, the energy released results in the high velocity at which the helium atoms are ejected. Translated into more familiar terms, the energy that would result from the complete annihilation of one pound of any given material would be equal to the energy obtained by burning 2 million tons of coal.

(32:7)

An example of the conversion of matter into energy has been present for millions of years. The heat and light from the sun originate from the destruction of the sun's own substance. For many years, there was no satisfactory explanation of solar energy. No process was known, such as burning or radioactivity, which could explain the continuous output of energy over such long periods of time. The theory is now accepted that the sun's radiation results from the annihilation of its own mass. The ratio of energy to mass is so great that even the huge quantity of radiation from the sun depletes its mass by only a minute fraction each year.

This mass-to-energy change in the sun takes place in the course of several nuclear reactions. Among the elements known to exist on the sun are carbon, hydrogen, and helium. In the process of releasing energy, a carbon atom adds four hydrogen nuclei to its nucleus, one at a time. As each new particle is added, radioactive changes take
place. When the fourth hydrogen nucleus is added, a helium nucleus or alpha particle breaks off, and the remaining particle is a carbon nucleus. A carbon atom has, therefore, absorbed four separate protons, welded them firmly together, and then tossed them out as a finished helium nucleus. The only particle that is used up in this process is the proton, and it is evident that plenty of these hydrogen nuclei must exist at the temperatures present on the sun. This process represents a loss of mass of about 0.024 mass units per reaction, which would release an enormous quantity of heat and light. All life on earth, therefore, owes its existence to a nuclear mass-energy transformation process. (31:36-40)

This process for obtaining energy would be impractical for use by man because a temperature in the order of 20 million degrees is necessary to keep it going. It would be very difficult, if not impossible, to obtain this high temperature. In any event, the cost would be so great that the process would not be an economic success. The artificial transformations of the lighter elements so far accomplished by man require much more energy to produce the reaction than is ever released as a result of the process. (34:66) Furthermore, there is no known method by which man can change large quantities of mass into energy artificially. This transformation takes place
spontaneously in only two substances that are known at present, one of which is the isotope, uranium 235, and the other a new, artificially produced element, plutonium, of atomic number 94, which is produced from uranium. (34: 17)

The Chain Reaction and Fission

The transformation is accomplished by an almost instantaneous process known as a chain reaction. It is somewhat similar to ordinary burning. A fire burns when wood is heated in the presence of air because the wood undergoes a chemical change that produces heat. This heat will heat more wood which will in turn undergo a chemical reaction that produces more heat. The new heat is more than enough to keep the wood burning and a form of chain reaction results. It has been discovered that one of the isotopes of uranium can be made to react in a like fashion to release nuclear energy. (16:109)

The element uranium was mentioned previously as having three isotopes. Of these the isotopes 235 and 238 are of most interest because they are the isotopes from which it has been possible to release large quantities of nuclear energy. The discovery of the process for releasing this energy was made by the Italian scientist, Fermi. After the neutron was discovered, he became interested in
bombarding various elements with these particles. The general result was that some radioactive isotope was produced, usually by the ejection of an electron or a positron from the nucleus of the atom being studied. The question then arose as to what would happen when the last element in the periodic chart was bombarded. Uranium has an atomic number 92; therefore, if the addition of an extra neutron would upset its nucleus in such a way that it would throw out a positron, the positive charge on the nucleus would be decreased by one, and the isotope of element 91 would remain. On the other hand, if electrons were ejected, the positive charge would become 93, and a new element, hitherto unknown to man, would be manufactured.

When uranium was actually bombarded with neutrons, a whole group of radioactive substances was discovered. Since none of these could be found the same chemically as the elements close to uranium in the atomic table, it was assumed that the element 93 had been produced. There was one disturbing factor about the experiments. Regardless of the purity of the uranium sample used, some of the elements near the center of the atomic chart always seemed to be contaminating the final product. Further study revealed that these elements were actually produced when the uranium was bombarded with neutrons. This was a startling
discovery, for it meant that the atom had been split about in half, a process which, up to that time, had not been considered possible. The name "fission" was given to the process. (67:94)

A quick glance at the atomic table reveals another fact. The uranium nucleus of isotope 235, the isotope that was assumed to undergo fission, contains 143 neutrons in addition to its 92 protons. The nuclei of the lower elements into which the uranium atoms explode contain jointly far fewer neutrons. This means a surplus of neutrons, and during the splitting of the uranium atom, some neutrons are thrown out. These neutrons can also cause other uranium nuclei to split, again producing more neutrons. If the splitting process should continue to multiply, it would take on the character of a chain reaction. By this process enormous quantities of energy could be produced.

To test this theory, a separation of the isotopes of uranium was accomplished. A small quantity of U-238 was first bombarded with a stream of neutrons. The recording instruments indicated that tremendous bursts of energy were being released at intervals. The U-238 was then removed from the testing machine and replaced by a tiny speck of U-235, all that was available at that time. The stream of neutrons was again directed on the target with spectacular
results. The instruments indicated that great quantities of energy were being given off at a nearly constant rate which was about 10,000 times as fast as in the case of U-238.

The energy released in this process is commonly expressed in terms of a special unit of measurement. This unit is the electron volt, or, as it is used in discussing the energy released by nuclear reactions, the Mev. or million electron volts. Technically, the Mev. would be the amount of energy that a single electron would acquire in falling through a difference of potential of one million volts. To compare it with the energy released by some more familiar material, TNT will be used as an illustration. TNT is usually considered a powerful explosive, yet the chemical reaction by which TNT releases its energy when a molecule of it is exploded produces about a single electron volt of energy. By comparison, the amounts of energy recorded by the instruments when uranium was bombarded with neutrons were in the order of 200 million electron volts or 200 Mev. (67:93)

The steadiness of the energy released when U-235 was bombarded indicated that if a sufficient quantity of this isotope could be produced, a chain reaction that would release large quantities of energy could be maintained. A neutron striking an atom of U-235 causes it to break
into two parts as shown in the accompanying diagram. These pieces of the element, F, appear as elements of lower atomic number, possibly barium, a metal of atomic weight 137, and the rare gas, krypton, of atomic weight 84. At the same time two or three neutrons, n, are released. These neutrons that are released may do any of three things; they may collide with neighboring atoms of U-235 to produce further fission as shown by n$_2$; they may strike a nucleus of U-238 as n$_3$; or they may miss all of the surrounding nuclei and escape from the uranium as n$_1$. The chain reaction does not ordinarily take place in U-238. The neutron striking the U-238 nucleus may undergo fission, but more often it will bounce away without being absorbed, or result in the formation of a new isotope. For fission to continue, it is essential to have present a sufficiently large mass of U-235. In too small a mass, the chain reaction dies out through loss of neutrons, just as a single piece of wood will cease to burn through loss of heat. The presence of a large proportion of U-238 also decreases the chance of a chain reaction taking place, so the isotopes had to be separated.

Whenever a sufficient quantity of U-235 is accumulated in a pure state, an atomic bomb is produced. This critical quantity has been estimated at from two pounds to hundred pounds, but the actual amount of material
needed is a closely guarded secret. If two quantities of subcritical size are suddenly brought together, stray neutrons from the surrounding air start chain reactions which sweep through the mass of material to produce a colossal release of energy.

Since the isotope of uranium used in this disintegration has an atomic weight of 235, and the combined weight of barium, krypton, and the three neutrons released is only 224, the process results in a loss of mass of 235 minus 224 or 11 mass units. In each pound of uranium used in the atomic bomb the loss through fission is about one
one-thousandth of a pound, but this is transformed into energy which is equivalent to that produced by burning 3 million pounds of coal. Burning one ton of coal a day, it would take over four years to burn 3 million pounds of coal. In the atomic bomb, the same amount of energy is released for each pound of U-235 used in only a fraction of a second. The concentrated heat energy raises the temperature to millions of degrees, the light for the moment is brighter than the sun, and the outrushing air blast is terrific. This energy is the greatest known to man, and the only method of increasing it would be to increase the quantity of material disintegrated. If fission through chain reactions could be produced in any other substance, it would be equally effective for use in atomic bombs. (34:15)

To produce an atomic bomb, one of two things had to be accomplished; either a sufficient quantity of U-235 must be separated from the other uranium isotopes, or some other fissionable material must be discovered. Since the United States was engaged in a war that would probably be won by the side that could first produce an atomic bomb, both processes were undertaken. (55:89)
The Separation of the Isotopes

In nature the three isotopes of uranium were so thoroughly mixed in the beginning that wherever uranium ore is mined, 99.2 percent is U-238; 0.7 percent is U-235; and less than 0.01 percent is U-234. This means that for every atom of U-235 present in an ore, there will be about 140 atoms of U-238. The separation of these isotopes is no simple matter. The exact method used has not been revealed, but it is possible to give a general idea of each of the processes. At present it is impossible to separate the isotopes by chemical means since all of the isotopes have the same chemical properties. Fractional distillation and the use of high speed centrifuges are not satisfactory methods because these isotopes are so nearly alike. This left two possible solutions to the problem, namely, gaseous diffusion and electromagnetic separation.

The gaseous diffusion process depends upon the fact that molecules and atoms in the gaseous state are all moving at high velocities. There is no particular direction to the movement, but the lighter particles tend to travel at higher speeds. This would indicate that the lighter particles are able to pass through a porous barrier somewhat easier than the heavier ones. Since uranium does not exist as a gas at ordinary temperatures, a compound, uranium hexafluoride, was used, and barriers of
different materials were tried. The exact material finally used is not revealed in the government reports. It is one of the things the United States paid $2,000,000,000 to learn.

A barrier consists of a box or tube of this porous material. The uranium compound is pumped into the tube at one end and removed at the other. Some of the compound diffuses through the walls of the barrier, and, since the lighter molecules get through easier, the material on the outside of the barrier contains slightly more of the lighter isotope. A mixture entering the separator as 99 percent U-238 and 1 percent U-235 would be enriched, theoretically, to 1.0043 percent U-235. In actual operation the percent of increase is not this high. A purity of 90 percent U-235 is essential to the manufacture of atomic bombs, so it is evident that the gas must be passed through a large number of barriers to be of any use. Actually, about 4,000 separator stages containing many acres of barrier surface are used before the gas of the desired purity is obtained. (55:174)

Added to the other engineering difficulties that are encountered is the fact that the gas used is a deadly poison. This means that all chambers through which the gas passes have to be absolutely airtight, and the whole process regulated by remote control. Also at the time the
plant was designed, no one had any idea as to the critical quantity of U-235 that could be present in the pure state without having an explosion. Since the gas in the final stages of this process contains a fairly high concentration of U-235, provision is made for its removal and isolation before any possible explosive quantity can accumulate.

The second principal method of separating the uranium isotopes is by use of electromagnetic separators called "calutrons." These machines make use of the principle that charged particles are bent from their original paths in passing through a magnetic field. Since lighter particles are deflected more than heavy ones, it is possible to concentrate the light particles at one spot and the heavy ones at another.

The two main parts of the calutron are a large electromagnet and a suitable source of charged particles or ions. The ion source that was developed is one of the secrets of the success finally attained, and, as such, is definitely a military secret. For illustrative purposes, the type of ion source previously used is described. It consists of a hot filament of a suitable metal for emitting electrons surrounded by a grid of fine wires to which a strong positive charge is applied. Electrons leaving the filament travel toward the positive grid at great
Electromagnetic Isotope Separator

Negatively Charged Plates

Beam of Ions

Mixed U-235 & U-238

Giant Magnetic Field

U-235

U-238

16:189

speeds. When a gas is introduced into this arrangement, it suddenly finds itself in a stream of high speed electrons. Any gas molecule that gets in the way of the electrons is hit violently, resulting in the loss of an outer electron. The particles of gas become electrically unbalanced by this process and leave the ion source as gaseous ions with a positive charge.

A metal plate to which a strong negative charge is applied is brought close to the ion source. This causes the positive ions to move toward the plate, and a small slit in the plate permits some of the ions to pass through it and to enter the field of attraction of a second similar plate. The velocity of the ions is again increased and most of them pass through the slit in this plate also. As a result, a narrow beam of high speed positive ions is
produced.

The beam is focused into the magnetic field produced between the poles of huge magnets. When they enter the magnetic field, all of the ions have identical charges and the same speed. Since a magnetic field tends to push the charged particles aside, the ion beam is bent into the form of a loop. If all the ions have the same weight, they will all follow the same path and end up at the same place, but the gas introduced in the calutron is a mixture of the isotopes of uranium, and the ions produced are not identical. The ions of U-238 are slightly heavier and are not pushed aside as easily as the ions of U-235. The U-238 ions swing wide in the magnetic field and are collected at one spot, while the path of the lighter ions is bent more, and they are collected at another spot. By this method a separation of the isotopes is accomplished that is nearly perfect in one step.

The chief disadvantage of this method of separation is the small quantity of material produced in a day. By the use of methods in practice when work started on the bomb, it would have taken one billion such machines several days to produce enough U-235 for a single bomb. A better source of ions and a more complete use of the ions produced resulted in an increase in the amount of U-235 produced. Another means of increasing the efficiency of
the machine is the use of several ion sources and several collectors with each electromagnet. Technical and engineering problems were overcome, and the calutron is now one of the chief instruments for isotope separation. (16:194)

The Production of Plutonium

While work was in progress with the various methods for separating the isotopes, a second group of scientists was trying to locate a substitute material for U-235. This material must be fissionable, and also capable of supporting a chain reaction. It was recalled that when U-238 was bombarded with neutrons, it released large quantities of energy at intervals. This seemed to indicate to the scientists that some of the U-238 atoms were actually undergoing fission. Further study revealed that when a neutron having sufficient energy strikes a U-238 nucleus and is captured by it, fission takes place. The main trouble is that most of the high speed neutrons that are produced by fission either miss the nuclei of the other atoms entirely, or else simply bounce off without being absorbed. No chain reaction is possible under these conditions. In the case of U-235, on the other hand, even slowly moving neutrons will cause fission to take place.

These same slow-moving neutrons have no effect on
U-238. They simply drift up to the nucleus of this isotope and then move away. If the neutrons are moving at a moderate speed, they can be absorbed by the U-238 nucleus, but fission does not result from this neutron capture. Instead, a series of radioactive changes is started. The U-238 first becomes U-239 which is radioactive and emits an electron. The loss of a negative charge from its nucleus converts the atom to element 93 which was named "neptunium" and designated by the symbol "Np-239." This element also gives off an electron and becomes the isotope of another element called "plutonium" or "Pu-239." It was then determined that Pu-239, like U-235, will fission in the presence of either fast or slow neutrons. If large quantities of plutonium could be produced, it would serve as a perfect substitute for U-235. Since it is not an isotope of uranium, but a different element entirely, it could be separated from U-238 by chemical means. This would reduce the need for the vast isotope separators previously described. (67:94)

Production of the new element began in 1942 in an ingenious and odd-looking structure called the "atomic pile." A pile is a mass of material containing uranium spread throughout a block of some substance that will slow down the neutrons that are produced in a fission to speeds at which they can be used. One of the greatest problems
in the construction of the pile was to determine what material to use as a moderator for slowing down the neutrons. The lightest element that could slow down the neutrons without absorbing them would be the best moderator. This indicated that the isotope of hydrogen having an atomic weight of two would be the best moderator, but it could not be produced in large enough quantities to be of use. Helium was eliminated because it exists neither as a solid nor liquid at ordinary temperatures. The element finally chosen was carbon in the form of graphite.

The first pile that was constructed consisted of slugs of purified uranium surrounded by blocks of graphite. The whole mass somewhat resembled a huge ball. Neutrons for the process were provided by the fission of U-235. When U-235 undergoes fission, large quantities of energy are released in addition to the few neutrons. In order to produce plutonium, neutrons having energies in the order of 25 electron volts are needed. The difference between the 200 Mev. neutrons produced during fission and the 25 volt neutrons needed for transmutation of U-238 into plutonium appears as heat in the pile. This heat was first removed by passing currents of air through the pile, but when larger ones were built, it was found necessary to use cold water to remove the excess heat. (28:27)

It is also desirable to have some control over the
The Atomic Pile

1. Hole for experimental neutron beam escape.
2. Holes in which uranium slugs are placed.
3. Moderators of graphite blocks.
4. Lead and ray proof cement.
5. Shield of special boron steel.
6. Control rods made of cadmium.
7. Neutron reflector of solid graphite.

(16:129)

speed at which the atomic pile works. This can best be done by building into the piles movable rods of some
material that can capture large numbers of neutrons. An ideal material for this purpose is cadmium. It is a metal and can easily be shaped into control rods. It is also capable of absorbing many neutrons without any undesirable effects. Rods of cadmium are incorporated in the blocks of graphite in a manner which allows them to be removed or inserted at will. As the control rods are inserted they capture more and more neutrons from the fission process until there are not enough neutrons being produced to maintain the chain reaction. The pile then ceases to operate. Removing the rods makes a larger number of neutrons available for reaction, and the speed of the process increases rapidly.

In the operation of the pile, it is not necessary to separate the isotopes of uranium. Purified slugs of the uranium ore containing both isotopes are fed into the pile at one end. Some of the U-235 undergoes fission and releases heat and neutrons. These neutrons are then slowed down by the graphite present in the pile, and the excess heat is removed. The slow neutrons either combine with a nucleus of U-238 to form plutonium or react with other atoms of U-235 to cause further fission. All of the U-238 is not converted to plutonium in passing through the pile. As a result, the slugs that leave the pile contain a mixture of the uranium isotopes and plutonium along with
undesirable fission products that result from the process. The slugs leave the pile under water and are conducted to a series of purifiers where the plutonium is removed. The uranium that remains is separated from other radioactive by-products and is fed back into the pile. (16:167)

The atomic pile and the materials that are extracted from it give off a whole group of dangerous radiations. Electrons, positrons, protons, and neutrons are all discharged from the freshly removed materials along with very penetrating gamma rays. As a result the materials are deadly poisons that can kill without even coming in contact with a person. All of these radiations except gamma rays and the neutrons are stopped by a few inches of concrete or metal. Neutrons and gamma rays are similar in their ability to penetrate almost any matter, and once the neutrons are slowed down, they can drift about in the air. After a short time, the neutron breaks down into a proton and an electron to become a regular hydrogen atom, but if a stray neutron enters the body of a person, it may react with some of the elements present, for example, sodium in the bloodstream, to generate a gamma ray. Large numbers of gamma rays can cause a painful death.

Elaborate precautions are taken around the piles to protect the workmen from radiation. The entire mass of the pile is enclosed in a huge block of boron steel and
specially treated cement several feet thick. This is further lined with graphite to reflect as many of the neutrons as possible back into the pile. The whole block is air-tight, and control of the pile is maintained from a distance. The same precautions are carried over into the purification process. The vats here are made of concrete several feet thick, lined with suitable materials. They are buried completely in the earth, and the purification process is conducted entirely by remote control. (35: 263).

By these methods it is possible to obtain enough fissionable materials to produce an atomic bomb. There was still one important question that had not been solved; how large a quantity of U-235 or Pu-239 can be accumulated in one spot without have an explosion? As the various methods of collecting these materials progressed, the question became of more importance, for, if too large a quantity of fissionable material were brought together accidentally, the whole region would be destroyed. It was also necessary to answer this question before the final bomb could be assembled.

The Bomb and Bomb Tests

The exact critical size of the uranium mass is still a top military secret, but apparently the figure is in the
order of two pounds. For illustrative purposes, assume that this is the critical mass that will cause an atomic explosion. Since a sphere is the smallest volume that any given mass can assume, the active portion of the bomb would be a small ball of material about 1.8 inches in diameter. In order to keep this charge from exploding, a cylindrical section about a half inch in diameter could be removed from the center of the ball. This would give two pieces of fissionable material well below the critical mass that would exceed the critical size and explode when they were brought together.

In actual construction, the two pieces would be cast separately and machined to fit together. The ball serves as a target, and the slug is fired into it by some type of gun arrangement. In order to hold the fissionable charge together as long as possible after the explosion has started, the ball portion of the bomb is surrounded by tin, lead, or some other heavy metal. In any bomb that was to be dropped on an enemy target, special precautions would be taken to destroy the materials of the bomb in case it failed to explode. It is probable that the larger portion of the bombs that were dropped on Japan consisted of explosive charges for scattering the bomb parts in case anything went wrong. Several types of fuses would be included to make detonation more certain. (16:211)
The General Essentials of an Atomic Bomb

After the bomb is released, the automatic firing device (4) explodes a charge of powder (5) causing the subcritical mass of plutonium (1) to move rapidly down the gun barrel (3) into position between the subcritical pieces of the sphere (2) which is surrounded by a ball of lead (6). The rest of the bomb is filled with an explosive (8) which will be detonated by the fuse (7) if the bomb fails to work properly.

(16:211)

The final assembly of the first bomb took place at Los Alamos, New Mexico, on July 16, 1945. A duplicate of the bombs that were to be used later was mounted on the top of a steel tower and fired by remote control. There was an explosion with three phases: first, a light many times brighter than the midday sun and intense heat; second, a violent pressure wave that traveled through the air; third, a sustained, awesome, roaring sound. The light and heat were most spectacular. A huge fiery cloud of many colors rushed 40,000 feet upward until it was scattered by the winds of the substratosphere. The blast
that followed knocked down two men who were standing behind the control hut five miles away. The steel tower itself simply disappeared. In its place was a crater half a mile long and a quarter of a mile wide burned out of the sand of the desert by the intense heat. (55:250)

Atomic Warfare

The bomb that was later dropped on Hiroshima was described as having more power than 20,000 tons of TNT by President Truman and the War Department. It was equivalent to 2,000 block-busters, or the raiding force of 2,000 superfortresses. The entire bomb has been estimated as weighing about 400 pounds, but more than four square miles or sixty percent of Hiroshima was destroyed by the single bomb. Only about one-tenth of one percent of the active mass of the bomb was changed to energy. (34:68)

Bomb tests were later made using various amounts of materials. These tests showed that increasing the size of the bomb does not seem to be of much use from a military standpoint. Bombs of the present size will completely destroy nearly any target against which they are likely to be used. It would probably be more economical to have two smaller atomic bombs than a single bomb twice as large. Atomic bombs would probably be of minor importance in actual combat. Tests indicate that they are not an
all-powerful weapon against naval formations, but it would be possible to sink an entire formation with a sufficient number of bombs. The second bomb used in the tests at Bikini was exploded a few feet below the surface of the water, and sank one battleship, one aircraft carrier, three smaller surface craft, and five submarines. In addition many of the other ships were contaminated by radioactive water and remained dangerous to human health after two years, but this bomb was exploded under ideal conditions and the true value of the atomic bomb against wide fleet formations is still in doubt. (20:156)

Against military formations, too, the bomb will be of no great value. The army believes that atomic bombs will seldom be used by an advancing force because of the radioactivity set up in the bombed area, and the threat of gamma ray poisoning if used on troops close by.

Atomic warfare will be most effective against factories and large cities. Such concentrated targets are ideal for attack with atomic bombs. If no further advances are made in the methods of delivery, a single plane, or at most five or six planes, each carrying an atomic bomb could completely destroy a large-sized city at a single blow. Five hundred or a thousand such planes would virtually annihilate an opponent in a single night’s operation. Atomic explosives may also be used in the
war-heads of long range rockets, against which there is no known defense. The extreme power and compact size of the bomb make the use of either planes or rockets unnecessary. A time bomb of atomic explosives could be smuggled into a country and carried into a city in a car or light truck. The bomb would not have to be placed closer to the target than a mile, and could be detonated by a time device or a radio signal. Since neither U-235 nor Pu-239 emits enough radiation to be detected at any distance, it would be very difficult to locate or detect such bombs.

(34:82-84)

Probably of more interest than the bomb from a military point of view will be the radioactive poisons that are produced by the atomic piles. These poisons could be collected as a fine dust and dropped on cities in a fashion similar to the present method of spraying insect-killing powder from an airplane. Similarly, a drone plane could be built with a type of jet engine powered by an atomic pile. It could be launched from a distance and controlled in its flight by radio. Since there would be no shielding to stop the emission of radioactive particles from the machine, it would be a small but effective poison factory. It could poison all of the personnel of a bomber formation by simply flying alongside for a short distance. By circling over a city, it would soon release enough
poison to wipe out all of the inhabitants. It would do no good to shoot down a plane of this type, for if it lit near the city, it would continue to release poisonous radiations that would wipe out the target. Submarines that could travel underwater for great distances and battleships of unlimited cruising range could also be powered by atomic energy.

In any event, the civilian workers stand to bear the brunt of atomic warfare as it is now developing. Decentralization of cities, factories, and production centers is the chief defense against the bomb, but even this will not remove the effectiveness of atomic warfare against civilian targets. No matter how widely dispersed the cities are, or how deeply buried in the earth the factories may be, these targets will still be vulnerable to attack. If the air around them and the water used for drinking or industrial processes are made radioactive, all human beings in that region will die. Water will spread radioactive poisons quite readily, and the radioactivity will remain in the water for a long time.

Civilian Uses of Atomic Energy

The immediate applications of atomic energy to civilian uses will be less spectacular. The only method that can be used at present for the utilization of atomic
energy is the atomic pile. The pile releases large quantities of heat. In the plants that were used in the manufacture of the atomic bomb, this heat was an undesirable and bothersome by-product that had to be removed by elaborate cooling systems. In the experimental plants that are now planned, this heat will be used in the same manner as the heat from burning coal. The energy of the pile will be used to heat some liquid which will then turn water into steam. This steam may be used to operate a standard turbine which will run a generator to produce electricity. Another means of using the energy from the pile would be to heat large buildings in congested areas where large heating plants are necessary. Here again the pile would be used to turn water into steam.

In each of the uses of atomic energy mentioned, the piles will be located at a fixed spot or else built into large pieces of equipment where weight is of minor importance. This is made necessary by the size of the pile used and the poisonous radiations produced. About the smallest pile that can be designed at the present time is one requiring 100 tons of shielding. This would be equivalent to walls of cement and steel about six feet thick. It would limit mobile units to large ships, and eliminate the possible use of such piles for the operation of commercial airplanes, automobiles, and locomotives.
Other factors also rule out the use of atomic energy for small operations. It is estimated that plants designed to operate on atomic energy will cost between $2,500,000 and $10,000,000. The removal of waste products from the atomic pile is also necessary, and this would require elaborate and expensive equipment. From an economic standpoint, it will be necessary to have a large market for power and heat before it will be profitable to construct such a plant. The use of atomic energy for heating purposes or the production of electricity will not lower the cost of these utilities to any great extent. Uranium is a fairly cheap fuel at $20 a pound, since it can produce as much energy as 1,500 tons of coal, but water power is free, and electricity is still rather expensive. It should be remembered that the cost of production is only a minor item in these utilities. Most of the expense lies in the plant, generators, switchboards, and lines for transporting the heat and electricity.

But power is only half of the story of atomic energy. The rest is an almost unlimited realm for the use of radioactive isotopes. Only a few of these radioisotopes occur in nature. Others can be made in small quantities but at great expense by machines such as the cyclotron. The atomic pile can make hundreds of them, in some cases, by the pound. Radioisotopes hold the greatest promise in
the fields of medicine and the study of life's chemistry. Since the radioisotopes are the same chemically as the other isotopes of the same element, they can be mixed into compounds of the element, and their course traced through any chemical reaction. If it is desired to know how phosphorus is used in the body, a small quantity of radioactive phosphorus is changed chemically to phosphoric acid. This is then mixed with a person's food, and its course is traced through the body without difficulty. (4:97-103).

Another use for these radioisotopes is in locating the source of certain organic diseases. For example, a person whose thyroid gland is not functioning properly may suffer from goiter and other diseases that are caused by an excess of thyroxine in the blood stream. Recently a young man who had been suffering from this condition was operated on and his thyroid gland was removed, but this did not stop the excess of thyroxine in his blood stream. Some other tissue in his body had taken over the manufacture of this chemical and was slowly killing him. The doctors could not tell where to look for this strange tissue, as it might be located in any part of the body. Radioactive iodine was called upon to locate this thyroxine-producing tissue. It is known that iodine will collect in the thyroid gland, so a small quantity of
radioactive iodine was injected into the blood stream of the patient, and after a short time a Geiger counter was brought close to him. As it was moved about over the patient's body, the counter suddenly began to record the presence of an unusual amount of radioactivity at one spot which proved to contain the malfunctioning tissue. Some of the other diseases that are being studied with the use of these materials are cancer and hardening of the arteries.

In industrial plants the radioisotopes are used to trace various elements and compounds through reactions. If it is desired to know where a certain element leaves a reaction, this point can easily be located by the use of a small amount of radioisotope of the element. Leaks in various industrial systems can be located in the same way. In the petroleum industry, radioactive carbon is being used to trace the paths taken by various hydrocarbons in the refining process. (15:56-59)

Control of Atomic Energy

Since ordinary uranium is the raw material for the production of atomic energy and will probably remain so for some time, an evaluation of the world supply of this metal is of importance. Uranium is very widely distributed in nature. The earth's crust consists of about 95
percent igneous rock, granite, and basalt, which contains 0.004 percent uranium, or about one-seventh of an ounce of uranium for each ton of rock. This would amount to $10^{15}$ (1 followed by 15 zeros) tons of the metal. The oceans are estimated to contain another ten billion tons of the metal. Compared with other more familiar elements, there is more uranium in the earth's crust than cadmium, bismuth, silver, mercury, or iodine. Uranium is about a thousand times more plentiful than gold. Ores containing as little as a fifth of an ounce of gold per ton are commonly mined, so, if society should decide that uranium is as valuable as gold, there is an extensive supply of the metal. While this is not a practical source of uranium from a financial point of view, there is little doubt that it could be mined from the rocks of the earth for the manufacture of implements of war.

There are also certain regions where the uranium ore is more concentrated, especially the Belgian Congo, where the world's richest deposits are located, and the northern territories of Canada. In these two regions, fifty tons of ore will often yield a ton of uranium. Other important deposits are located in Brazil and Czechoslovakia, with fields of less importance in Norway, Sweden, Germany, Italy, Russia, France, and the United States. In other words, no one nation has a monopoly on the uranium deposits
of the world, and any one of them could produce enough of
the mineral to make many bombs and other implements of
atomic warfare. (34:45-47)

Since there is no defense against atomic warfare, and
it is likely that any nation will be able to produce atomic
weapons in a few years, it is logical that some measures
be taken to control the use of uranium. Niels Bohr has
expressed this opinion very well when he said:

The formidable means of destruction which
come within reach of man will obviously con-
stitute a mortal menace to civilization unless,
in due time, universal agreement can be obtained
about appropriate measures to prevent any un-
warranted use of the new energy sources. An
agreement to this purpose will surely demand the
abolition of barriers hitherto considered neces-

tary to protect national interests but now
stand in the way of common safety against un-
precedented dangers. In fact, only inter-
national control of every undertaking which
might constitute a danger to world security will
in the future permit any nation to strive for
prosperity and cultural development without
constant fear of disaster. (14:363)

The plan that offers the greatest promise is, then,
one which proposes that an international authority be
created with control over all uranium deposits. It is
possible to make U-235 and Pu-239 both unsuited for ex-
plosives without destroying their value as a fuel. The
control commission would mine, purify, and denature the
uranium and plutonium. Only the denatured product would
be sold to individual nations.
This means that the individual nations would have no control over the uranium deposits lying within their boundaries. It also implies that the world authority could pass at will across national barriers and inspect any region where uranium deposits might be located. Furthermore, all factories and research laboratories where uranium is used would be subject to inspection. Any nation that was found to be violating the regulations of the authority would immediately have its supply of uranium and plutonium shut off. Obviously any nation that was planning an atomic war would first seize the fuel plants within its own boundaries and would therefore give warning of its intentions. Other nations should then be able to stop the warlike actions of the offender before much damage could be done.

Nations could well profit by the example of the discovery of atomic energy. This was an international project in which the scientists of many nations took part. Cooperation between nations and individuals was the guiding principle. If all nations could learn the same lesson, there would be no need for atomic weapons, and the energy of the atom could be dedicated to peace.
Alpha particle: a helium nucleus, traveling at high speed, which appears when some of the radioactive substances break down or disintegrate.

Atom: the basic unit of matter in chemical reactions. It consists of a heavy nucleus and surrounding electrons.

Atomic number: the number of positive charges on the nucleus of an atom. This determines the chemical nature of the atom.

Atomic weight: the weight of the atom is determined by the weight of the nucleus and is nearly equal to the total number of protons and neutrons in the nucleus. The basic unit of weight is one-sixteenth the weight of a common oxygen atom.

Beta particle: very high speed electrons given off by the nucleus of a beta-active radioactive element when it breaks down.

Chain reaction: a reaction, chemical or nuclear, in which the energy or particles generated by the breakdown of the first atom or molecule causes the breakdown of one or more additional atoms or molecules whose reaction in turn causes other atoms or molecules to disintegrate.

Control rods: rods of neutron-absorbing material used in a pile to control the chain reaction.

Critical mass: the minimum amount of a given fissionable material required for a spontaneous chain reaction. With less than this amount the loss of neutrons is too great to result in a chain reaction.

Diffusion: the movement of molecules through a gas, liquid, or solid, due to the natural motion of the molecules.

Disintegration: the process of spontaneous nuclear change in which alpha particles, beta particles, or positrons are given off from the nuclei of atoms.
Electron: the unit particle of negative electricity, weighing one-eleven thousandth as much as a proton.

Electron volt: The unit of energy used in nuclear science. Nuclear reactions usually involve energies of millions of electron volts, while chemical reactions involve energies of only a few electron volts.

Element: A kind of matter that is not decomposed by any kind of chemical reaction; a kind of atom with a given atomic number.

Fission: the process by which the nucleus of an atom is split into several parts, at least two of which are of roughly comparable size, greater than that of the alpha particle.

Fission product: an isotope, usually radioactive, of an element in the middle of the periodic table and produced by fission of a heavy element such as uranium.

Gamma ray: penetrating invisible light-like radiation given off from the nucleus of an atom when "excited." Usually more penetrating than ordinary X-rays.

Ion: an atom or molecule that carries an electric charge.

Isotopes: atoms of a given element which have different numbers of neutrons in the nucleus and therefore differ in mass or weight.

Mass: effectively the same as weight.

Mass number: the number of protons and neutrons in a given nucleus; approximately the weight of the nucleus.

Moderator: material containing atoms of low atomic weight used in the pile for slowing down neutrons by collision.

Neptunium: element number 93, usually produced artificially. Isotope Np-239 is the radioactive parent of Pu-239, an atomic explosive.

Neutron: a nuclear particle of weight about one unit, which is electrically neutral.

Nucleus: the central core of the atom in which almost all of the weight is located.
Pile: a controlled fission chain-reacting system, usually consisting of uranium or plutonium intermixed with a moderator such as graphite together with all the neutron reflector, shielding, cooling, and control systems.

Plutonium: element number 94, usually produced artificially.

Positron: positive electron; appears in certain decays of radioactive substances and in cosmic radiation.

Proton: the atomic nucleus of ordinary hydrogen. It is a component part of atomic nuclei of all other elements. Number of protons in a nucleus determines the nuclear charge or atomic number.

Radiation: particles, X-rays, gamma-rays, or light moving between or past atoms, and not part of their stable structure.

Radioactivity: the process of giving off radiation during the disintegration of atomic nuclei.

Transmutation: the process of changing an atomic nucleus to one of different atomic number or atomic weight by bombardment with nuclear particles from the outside, as in the cyclotron or pile.
Chapter III

The Teaching Unit

Special Equipment Needed in Presenting the Unit

The introduction of this unit into the science course will call for some special preparation on the part of the science teacher, and will entail some added expense. An original expenditure of $100 or $150 could well be approved for the introduction of this unit, but this would probably restrict the study of atomic energy to larger high schools. The equipment described and experiments outlined in this unit are inexpensive and within the limits of the budget of the average school. If better equipment is available, other experiments can be devised by the competent high school science teachers.

It is also quite possible that some of the better pupils will become interested in building various pieces of equipment that can be used in studying atomic energy. Two instruments that have been constructed by high school pupils are simple Geiger counters and cloud chambers. Useful exhibits have also been developed on the release of atomic energy and the atomic bomb.

A Wilson cloud chamber is an essential piece of equipment in presenting this unit. These instruments can be obtained in a wide variety of shapes and prices, but
the bulb type chamber is satisfactory for high school use. A simple magnifier of from five to fifteen power and a powerful magnet are needed to perform the accompanying experiments. If it is possible to obtain a gold leaf electroscope having an ionization chamber and a graduated scale for measuring the rate of discharge, some very interesting experiments can be worked out to illustrate the rates at which various radioactive elements discharge the instrument.

A supply of radioactive materials is also necessary. The radioactive isotopes from the atomic pile are not available for high school use; therefore, the radioactive materials that occur in nature must be used. A small quantity of a few of these elements having fairly long half-life periods is quite useful. These can be obtained either as prepared slides or as powdered salts from a number of commercial supply houses.

About one milligram of polonium is needed for the experiments that accompany this unit. This will have to be replaced each year as polonium has a half-life of 138 days. One possible source of this element is the radon needles used for the treatment of cancer. Radon deteriorates quite rapidly, having a half-life of 3.8 days; consequently, the needles soon lose their potency. It is sometimes possible to obtain these worn-out needles free
of charge from hospitals. The worn-out needles are high in polonium content, and this polonium can be extracted by crushing the needle in hydrochloric acid. The polonium dissolves and is then deposited out on a nickel wire by simply dipping the wire into the solution. Polonium can also be purchased from commercial supply houses.

Suggested Procedure

Most pupils will begin the study of a unit on atomic energy with some previous information on the subject obtained by reading magazines and newspapers. Much of this information will be false or at least quite distorted. The teacher must be on the alert for wrong impressions that have become fixed in the minds of the pupils and tactfully supply the correct interpretation to the material which the pupil presents.

It is suggested that a general picture of the entire unit be given during the first two or three class periods and then special emphasis be placed on the individual topics. Visual aids should be used for both the overview of the subject and in development of the special topics. Class reports should be illustrated with drawings and pictures whenever possible.

The most difficult concepts for the pupils to understand are those concerning the size and structure of the
atom. For this reason it is suggested that each pupil be given the opportunity to observe the scintillations that occur on a zinc sulfide screen when bombarded with alpha particles. Every pupil should observe the cloud tracks left by charged particles traveling through an expansion chamber. The concepts about the release of atomic energy cannot be verified by experiments in the high school laboratory, but many articles have appeared in books and magazines on the basic principles of atomic energy, and the student should learn to be critical of the authors on the subject. High school juniors and seniors should no longer believe everything they see in print, but should find out about the author's qualifications for writing on the subject.

Objectives of the Unit

The general objectives of the unit are:

(1) To give the pupil an understanding of the structure of the atom.

(2) To acquaint the pupil with the experimental procedure by which the release of atomic energy was discovered.

(3) To give a general picture of the development of the atomic bomb.
(4) To correct false impressions about the atom, atomic energy, and the atomic bomb.

(5) To show the need for international control of atomic energy.

(6) To make the pupil eager for more knowledge about the subject.

Possible Approaches

A. Through motion pictures:

Motion pictures that can be used in developing this unit are listed in a later section on "Materials for Instruction." The following pictures from this group would be especially useful in introducing the unit to the pupils.

1. Operations Crossroads
2. Atomic Power
3. A Tale of Two Cities

B. Through the bulletin board:

The new exhibit, usually planned by two or three pupils and supervised by the teacher, is placed on display a few days before actual study of the unit begins. This gives all of the pupils a chance to observe the bulletin board and make suggestions as to changes or additions to the material found there. The bulletin board should not be used as the only means of introducing the unit, but should be supplemented by other approaches. Many useful
illustrations are found in the following references listed in the bibliography: 4; 6; 13; 20; 27; 36; 40; 46; 49; 54; 60; 64; 65; 66; 67.

C. Through demonstration experiments:

1. The Wilson cloud chamber; its use, demonstrated by the teacher, should raise questions as to why the machine works, and, in turn, to radioactivity and the structure of the atom.

2. Student projects; a student who has been working on some special tool for studying the atom, such as a Geiger counter or model Van de Graaff generator, could introduce the unit by demonstrating the operation of his machine.

D. Through reading interests:

1. Some of the more fantastic articles listed in the bibliography could be read and reported to show the popular ideas about the subject. The study would then go on to show the true nature of atomic energy. Articles that would be useful in this way are: 10; 13; 17; 21; 39; 40; 44; 47; 68.

2. Current newspaper and magazine articles.

3. Reports on new development in atomic energy.

E. Through guest speakers:

1. Secure as a speaker some person who was present at one of the bomb tests.
2. Secure as a speaker a member of the military forces who has visited either Hiroshima or Nagasaki after they were bombed.

3. Secure as a speaker any person who has had personal experience with the development of atomic energy.

G. Through observation trips:

This approach will be limited to the few schools that are located near an atomic energy plant or research laboratory. The teacher should not expect to take a whole class on a field trip to either a laboratory or plant, but occasionally two or three of the better pupils in the school can be taken on short tours and can then report their experiences to the class.

Most teachers will not be satisfied with any one method for introducing the unit, but will combine several of the suggested approaches. For example, the bulletin board could be prepared a few days in advance of the beginning of the unit. One of the motion pictures could then be shown, followed by a talk by a guest speaker. The pupil should then be ready to make a thorough study of the unit.
Presenting the Unit to the Class

**Concepts**

1. All matter is made up of atoms that are in turn composed of protons, electrons, and neutrons.

2. It is possible to transform one element into another by making changes in the atomic nuclei.

**Activities**

1. Research activities:
   
   a. Reading and reporting.
      
      (1) Unit text; Section 1
      
      (2) Reference books;
      
      16:5-72
      
      29:3-105
      
      32:3-6
      
      34:7-15, 22-24
      
      (3) Magazine articles;
      
      17; 46; 49; 51.

   b. Motion picture; The Electron.

2. Laboratory activities:

   Experiment 1#. Counting Atoms

3. Construction activities:

   a. Charts and drawings showing the structure of the atom.

   b. Models of atomic nuclei and simpler atoms.

*Note: This and all following experiments are found in the section on "Materials for Instruction."
3. The various tools used to study the atom make use of simple principles of physics.

1. Research activities:
   Reading and reporting.
   (1) Unit text; Section 3.
   (2) Reference books; 
       23:109-117
       29:92-105, 124-135
       30:44-54
   (3) Magazine articles; 
       3; 8; 15; 17; 27; 
       53; 54; 60; 64.

2. Laboratory activities:
   Experiment 3. Wilson Cloud Chamber.
4. Mass is a form of energy that can be converted into other forms of energy.

3. Construction activities:
   a. Bulletin board showing pictures and diagrams of the cyclotron, Van de Graaff, Geiger counter, and other tools used to study the atom.
   b. Student-built cloud chamber:
      59:221, 503
   c. Geiger counter:
      59:504-507
   d. Model Van de Graaff
   e. Model cyclotron

1. Research activities:
   Reading and reporting.
   (1) Unit text; Section 4.
   (2) Reference books;
      16:72-89
      23:79-97
      30:55-88
      32:7-10
      55:2-5, 17-18
   (3) Magazine articles;
      10; 17; 18; 21; 31; 40.

2. Drill activities: Use tables of isotopes to show the amount of mass that represents the binding energy of the nuclei of various atoms. See unit text, page 32.
Nuclear energy may be released by atoms that undergo fission, and useful energy is obtained if a chain reaction can be maintained.

A high concentration of U-235 or Pu-238 is needed for the manufacture of atomic bombs; however, energy may be released from the mixed isotopes of uranium by means of the atomic pile.
2. Construction activities:
   a. Drawings to show the construction of the atomic pile.
   b. Bulletin board: Especially items that tell of current developments.

7. Atomic energy may be released either for the benefit of man or for his destruction.

1. Research activities:
   a. Reading and reporting.
      (1) Unit text; Sections 7 and 8.
      (2) Reference books:
           16:200-243
           23:150-179
           32:23-26
      (3) Magazine articles:
           2; 4; 9; 11; 12; 13; 19; 20; 22; 24; 25; 35; 36; 38; 39; 41; 42; 43; 45; 48; 56; 58; 60; 61; 63; 65; 66; 68.
   b. Motion pictures:
      A Tale of Two Cities
      Operations Crossroads
      One World or None
   c. Slide film:
      One World or None

2. Construction activities:
   (1) Construction of a dummy atomic bomb.
   (2) Drawings and posters to illustrate various uses of atomic energy.
8. International control of the uranium supply and the purification of U-235 and plutonium will lessen the danger of atomic warfare.

1. Research activities:
   
a. Reading and reporting:
      
      (1) Unit text:
          Section 9
      
      (2) Reference books:
          16:261-297
          34:45-49, 135-234
      
      (3) Magazine articles:
          5; 7; 22; 26; 33; 37; 52; 57; 62; 68.

   b. Motion pictures:
      Atomic Power
      One World or None

   c. Slide films:
      How to Live with the Atom.
      World Control of Atomic Energy
      One World or None.

2. Construction activities:
   
   Posters to show the need for international control.

Culminating Activities

The culminating activities should bring together all of the information that the pupil has studied in the unit in a summary form. No one activity will be satisfactory.
for every class or every situation. The teacher will have to choose the type of summary best suited to his particular group. Some culminating activities that have been used with success are listed below.

1. Motion picture: Show one of the following films to help review the basic concepts of the unit. Students, with the aid of the teacher, should attempt to draw satisfactory conclusions regarding the importance of the use and control of atomic energy in modern civilization.
   a. Atomic Power
   b. Atomic Energy
   c. One World or None

2. Slide films: Use the same procedure as for motion pictures. Slide films that could be used are:
   a. How to Live with the Atom
   b. World Control of Atomic Energy
   c. One World or None

3. A student exhibit: This would consist of all of the construction activities worked on during a study of the unit presented as a display for other pupils in the school to observe. If an especially good exhibit is prepared, it may be given space in a local store window for the
pupils' parents and other interested town people to see. One exhibit that was prepared by high school pupils is outlined in a later section.

4. Assembly program: Students organize and present an assembly program on atomic energy to show the need for a better understanding of the subject.

5. Panel discussion: Cooperate with the social science or English class to present a panel discussion on one of the following subjects:
   a. Public vs. private ownership of atomic power plants.
   b. Current federal legislation on atomic energy.
   c. International control of atomic energy.
   d. Security through secrecy vs. security through achievement.

6. Class movie: Have the class work out and film a motion picture similar to one they have seen on the subject or an original of their own.

Measurement of Learning

Much of the material studied in this unit is factual, and the pupil's knowledge of the facts can be measured by objective tests. The pupil should also be able to apply the facts he has learned to daily situations. His ability to do this can be determined either by essay type
examinations or by problem-solving types of objective ex-
aminations. One type of examination that has been used
tests the pupil's ability to apply the knowledge he has
gained to criticizing a sample magazine article written
by the teacher.

Tests are only one way of measuring the pupil's
achievement. His classroom activities and preparation
are recorded on a progress report sheet, and he should be
given credit for special projects or research. His re-
port on outside reading should be graded on delivery, ap-
propriateness, and interest. His laboratory work should
be graded for neatness, accuracy of observation and cor-
rectness of conclusions.

Materials for Instruction

1. The school exhibit: purpose, to present the basic
facts about atomic energy and the atomic bomb to pu-
pils not registered in science classes. (This ex-
hibit was prepared by the pupils of Central High
School, Philadelphia, Pennsylvania.)

a. A wall chart of an atom with its nucleus and
shells formed the background for the exhibit.
The nucleus was shown as black and white dots and
the shells as different colored concentric bands.
b. Models as follows were arranged in a suitable manner in the showcase accompanied with cards telling what they represented:

(1) hydrogen atom.

(2) nucleus of U-235. This was an amber-colored Christmas tree ball filled with the appropriate number of black and white beans to represent protons and neutrons.

(3) nucleus of U-238. Similar to U-235, but using a red ball.

(4) similar to model 2, but depicting radioactivity.

(5) showing U-235 being bombarded with neutrons.

(6) representing the nucleus of U-239 as a blue ball similar to those above.

(7) showing a broken blue ball with the contents scattered to represent fission.

The second part of the exhibit was a model of an atomic bomb with an explanation of how it worked. (For a complete description of the exhibit with all of the information contained on each card see bibliography reference 1.)

2. Visual Aids:

Motion pictures:

a. A Tale of Two Cities (20 minutes), Signal Corps Film Library, Presidio, San Francisco, California.

This picture shows the destruction caused by the atomic bombs at Hiroshima and Nagasaki.
b. Operations Crossroads (27 minutes), Motion Picture Section, Office of Public Information, Navy Department, Washington, D. C.

This is a joint Army-Navy Task Force film on the Bikini experiments. It is in color with sound and shows dramatically all of the information that has been released on the bomb tests.

c. Atomic Power (17 minutes), The March of Time, 369 Lexington Avenue, New York City.

The story of atomic power from Einstein to the atomic bomb is told. It shows the actual scientists at work and concludes with an appeal for control of atomic power.


This film describes in graphic animations how nuclear synthesis, fission, and the bomb's chain reaction are accomplished.

e. One World or None (9 minutes), Film Publishers, Inc., 25 Broad Street, New York 4, New York.

The destructive power of the atomic bomb is stressed in this film, and a strong appeal for social and political action to insure that atomic knowledge will not be used in the future for destructive purposes is voiced.

Slide Films:

a. How to Live with the Atom, National Committee on Atomic Information, 1749 L. Street N. W., Washington, D. C.

b. World Control of Atomic Energy; same source.

c. One World or None; same source as motion picture.
Experiment I - Counting Atoms

This is a group experiment to be carried out over a period of a week or more.

Objective of the experiment: To determine the approximate number of atoms in a given amount of material.

Method of procedure: When a radioactive element disintegrates, it ejects charged particles that can be detected. If these charged particles are alpha rays, they will cause a flash to appear on a zinc sulfide screen each time a particle is ejected. Since each flash represents the death of the original atom, it is possible to count the rate at which the atoms of the material are used up. From these data, the approximate number of atoms of the radioactive element present in the original sample can be obtained. For this experiment polonium is used.

Directions:

(1) Dissolve one milligram of polonium in a drop of nitric acid. Dilute the solution to 50 ml. and pour off all except 5 ml. of the diluted solution. Again dilute this sample to 50 ml. and pour off all but 5 ml. Repeat this process until a 5 ml. portion of the solution contains 10^-14 grams of polonium. Make a record of your data as follows:

<table>
<thead>
<tr>
<th>Original sample is</th>
<th>10^-3 grams of Po.</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 ml. of 1st dilution contains</td>
<td>10 grams</td>
</tr>
<tr>
<td>5 ml. of 2nd dilution contains</td>
<td>10 grams</td>
</tr>
<tr>
<td>5 ml. of 3rd dilution contains</td>
<td>10 grams</td>
</tr>
<tr>
<td>4th</td>
<td>10 grams</td>
</tr>
<tr>
<td>5th</td>
<td>10 grams</td>
</tr>
<tr>
<td>6th</td>
<td>10 grams</td>
</tr>
<tr>
<td>7th</td>
<td>10 grams</td>
</tr>
<tr>
<td>8th</td>
<td>10 grams</td>
</tr>
<tr>
<td>9th</td>
<td>10 grams</td>
</tr>
<tr>
<td>10th</td>
<td>10 grams</td>
</tr>
<tr>
<td>11th</td>
<td>10 grams</td>
</tr>
</tbody>
</table>

(2) Mix about 10 milligram of finely divided zinc sulfide with enough distilled water to form a thin paste. Spread this paste on a glass plate to form a reasonably uniform layer on a
spot about the size of a dime. Do not make the spot too large, as it will be difficult to concentrate on a large area when counting the flashes. Add 5 ml. of the final polonium solution to the spot of zinc sulfide. This solution must be added a drop at a time, letting each drop dry before putting on the next drop to prevent spreading the zinc sulfide over a larger area.

When the required 5 ml. of solution has been added, the glass plate is taken into the darkroom. It is necessary to have as nearly absolute darkness as possible in this part of the experiment in order to see the flashes on the zinc sulfide screen. Place the screen under a hand magnifier or low-powered microscope with the entire screen in focus. Tiny flashes should then be visible on the screen. They will probably be irregular, with several appearing at almost the same instant and then several seconds passing before another flash appears.

Count the flashes that appear during 5 one-minute intervals. Rest your eyes between each period of counting. Record your observations in the following table:

<table>
<thead>
<tr>
<th>No. of Flashes</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1st minute</td>
<td></td>
</tr>
<tr>
<td>2nd minute</td>
<td></td>
</tr>
<tr>
<td>3rd minute</td>
<td></td>
</tr>
<tr>
<td>4th minute</td>
<td></td>
</tr>
<tr>
<td>5th minute</td>
<td></td>
</tr>
<tr>
<td>Total (_1)</td>
<td></td>
</tr>
<tr>
<td>Times (_1)</td>
<td>12</td>
</tr>
<tr>
<td>Total</td>
<td></td>
</tr>
<tr>
<td>(\text{flashes per hour} ) (\text{(A)})</td>
<td></td>
</tr>
</tbody>
</table>

After the class has completed this part of the experiment, put the screen aside for one week and again count the number of flashes as above.

<table>
<thead>
<tr>
<th>No. of Flashes at End of 7 Days</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1st minute</td>
<td></td>
</tr>
<tr>
<td>2nd minute</td>
<td></td>
</tr>
<tr>
<td>3rd minute</td>
<td></td>
</tr>
<tr>
<td>4th minute</td>
<td></td>
</tr>
<tr>
<td>5th minute</td>
<td></td>
</tr>
<tr>
<td>Total (_2)</td>
<td></td>
</tr>
<tr>
<td>Total flashes per hour at end of one week (\text{(B)})</td>
<td></td>
</tr>
</tbody>
</table>
The number of atoms used up in one week would be equal to the total flashes per hour in the original counting times 24 times 7.

This caused a drop in the number of flashes per hour equal to the original total minus the total flashes per hour at the end of one week.

\[
\text{The rate of drop is equal to } \frac{(\text{Total A} - \text{Total B})}{\text{Total A}}
\]

The total number of polonium atoms in the original sample would be equal to the total flashes per week times the reciprocal of the rate of drop. The number of atoms of polonium per gram of the original material would be found by multiplying this figure by $10^{14}$.

\[
\begin{align*}
\text{Total flashes per week} & \quad \text{Times the reciprocal rate} \\
\text{Equals number of atoms} & \quad \text{of polonium in samples used} \\
\text{Times} & \quad 10^{14} \\
\text{Equals} & \quad \text{atoms of polonium in one gram of original sample}
\end{align*}
\]

If a fresh sample of polonium is used, and the experiment is conducted in an accurate fashion, the total number of atoms in a gram of the original material should be about $2.37 \times 10^{21}$. 
Experiment II - Charged Particles

Objective of the experiment: To study the nature of the particles emitted by a sample of polonium.

Method of procedure: Three properties of the particles will be studied; namely, their range or distance they will travel in air, kinds of paths taken in air, and the effect of a magnetic field on the particles.

Directions: Prepare a screen by spreading a thin layer of zinc sulfide on one side of a piece of glass about two inches square. Dip the end of a needle into a small quantity of polonium so that some of the material adheres to the point of the needle. Fasten the zinc sulfide screen and the needle to separate blocks as shown in Figure 1. Be sure that the point of the needle is about even with the center of the screen, but do not touch the end of the needle to the screen. Bring the tip of the needle to within one-half inch of the screen and focus the magnifier on the center of the screen. Darken the room and observe the flashes through the magnifier. Report what you observe in the space below.

(The student should report many flashes near the center of the screen, with an occasional flash some distance from the center.)

Slowly move the block holding the polonium sample away from the screen and stop when the flashes no longer appear on the screen. Measure the distance from the point of the needle to the screen and report this distance below.
The flashes on the zinc sulfide screen are caused by alpha rays that can travel about (1.5) inches in air.

Move the point of the needle until it is one and one-fourth inches from the center of the screen. Make a small hole in the center of a piece of cardboard and place the hole in line with and half way between the point of the needle and the center of the screen as shown in Figure 2. Darken the room and observe where the particles strike the screen.

Do most or all of them strike the screen at the same spot?

Answer: (Most)

How would you account for this fact?

Answer: (Most of the particles travel in straight lines, but a few are deflected by atoms in the air.)

Without changing the arrangement of the apparatus used in the previous section, bring the space between the poles of a powerful magnet in line with the point of the needle and the cardboard. The particles should now be traveling through a strong magnetic field. Observe the point on the zinc sulfide screen where the particles are striking. Does it move when the magnet is moved? Why?

Answer: (Yes, because the alpha particles are charged particles and charged particles are deflected by a magnetic field.)

Write a short paragraph telling what you have learned about the rays given off by polonium.

Answer: (Polonium sends out charged particles that produce flashes on a zinc sulfide screen. These particles travel about 1\(\frac{1}{2}\) inches in air and most of them travel in straight lines.)


Experiment III - The Wilson Cloud Chamber

NOTE: This experiment will vary with the type of cloud chamber used. Follow the directions that came with your instrument.

Objective of the experiment: To study the paths of charged particles.

Method of procedure: A cloud chamber is, briefly, a glass bowl partly filled with water and provided with some means of suddenly expanding the air in the chamber. Sudden expansion cools the air causing it to become supersaturated. Charged particles traveling through this supersaturated air leave fog trails behind.

Directions: The cloud chamber should be set up according to the directions that came with the instrument. A strong beam of light is focused on the air in the cloud chamber in such a way that it is not reflected back at the observer. Darken the room and allow the air above the water to expand several times to clear it of dust particles.

Compress the air and hold it for a few seconds to allow the air within the chamber to return to room temperature. Let the air expand rapidly and watch the section close to the radioactive material for signs of cloud tracks. These tracks will remain for only a very brief time; therefore, close observation is necessary.

If possible change the source of radiation and repeat the experiment. Note any differences in the cloud tracks. Make two drawings below to show what you observed in the cloud chamber.

Drawing # 1 Drawing # 2
Study the pictures of cloud chamber experiments that can be found in books and magazines and note the different kinds of paths. Observe particularly that some of the particles are deflected by striking the nuclei of atoms in the air. How does this explain the fact that some of the alpha particles in experiment 2 struck the screen at some distance from the center?
BIBLIOGRAPHY


A complete account of an exhibit that was used to present the basic facts about atomic energy to high school pupils not registered in science classes. The exhibit was student designed and constructed.


A popularized account of the use of radioisotopes in the study of life processes and diseases.


An illustrated article that shows the basic construction of the counter tube and explains its operation by means of drawings. Also included are pictures of a variety of different types of special counter tubes.


The developments that have been made in the use of atomic energy both for power and in medical and industrial research. Well illustrated.


A brief but well written outline of the plan suggested by Bernard Baruch for the control of atomic energy.


A brief description of the atom and atomic fission. Well illustrated.

Several scientists contributed to this article in an effort to impress upon the nation their views on the future of the atomic bomb. It points out that there is no defense against the bomb, no secrets that cannot be solved by other nations, and no monopoly on raw materials; therefore, control is necessary.


A brief description of the synchrotron and its use in atomic research as compared with the cyclotron.


This article takes the reader away from the atomic bomb and presents the benefits that have resulted from the Manhattan Project. It points out the many machines and processes that have been perfected in the course of atomic research and the uses of the by-products in medicine, industry, biology, and genetics. The article is written for the non-technical population.


An outline of the material contained in the Smyth report written in a style suitable for high school students. It tends to emphasize the more spectacular features of the development.


A record of an interview with Lise Meitner in which she expresses her opinion on atomic energy and the atomic bomb.

The article presents the possibilities of offensive naval warfare that have developed as a result of the release of atomic energy.


One of the first articles on the atomic bomb to appear in a magazine of national circulation. Speculation as to the possible use of the bomb on future warfare with opinions expressed as to how military and naval operations would have to be altered. Some of the ideas expressed here were later changed in view of further developments.


A short article in which the author views with alarm the suppression of scientific knowledge obtained in developing the atomic bomb and expresses the hope that scientific progress will lead to harmonious relationships between nations.


A good description of the Geiger counter. It tells how this instrument operates, and how it is used around an atomic pile or other source of radioactivity.


This book is divided into three sections on the quest for atomic knowledge, making the atomic bomb, and the future of atomic energy. It takes most of its basic information from the Smyth report and presents it in a logical and easily understood manner.

17. Chubb, L. W. Giving the atoms the third degree. Popular Mechanics 76:8-11, Nov. 1941.

A pre-atomic age article that illustrates the experiments that were being performed with
radium products and the type of research that led to the development of atomic power.


A brief report on the structure of the atom and atomic fission that was especially designed for high school pupils.


The use of radioactive elements obtained by bombardment of various materials in atom smashers is explained in an elementary style.


An official account of the Bikini tests with a comparison of the effect of similar bombs if dropped on New York City.


Another popularized article that attempts to explain atomic fission. Several scientific principles are taken for granted, with no attempt made to explain them.


This article explains the latest developments in the attempt at international control. It outlines the United State's proposals, and the Russian objections to them.


A popularized account of the development of atomic energy that was written for the layman. This book is the type of article that would be of interest to high school pupils. It covers the Smyth report and goes on to make predictions as to future uses of atomic energy.

A survey of the recent research that has been published in more technical journals is reported in language that is easily understood by high school pupils. The use of radio-isotopes in the study of life processes and diseases is explained.


Radiation from radioactive isotopes that result from fission is described as being deadly and the precautions taken in handling radioactive material are illustrated with pictures and explanations.


An authoritative survey of the possible means of defense against the atomic bomb. The author concludes that no effective means has been devised to defend a nation against the bombs.


A reporter records his observations on a trip through the Oak Ridge atomic energy research laboratory and explains how fission products and radioactive isotopes are handled by remote control.


An authoritative article that describes the construction and operation of an atomic pile.


This is a popular guide to modern physics that gives the average man an opportunity to understand how some of the modern concepts of the atom were obtained and verified.

The author presents much of the technical information included in the Smyth report in language that is more easily understood and raises some ethical questions as to the use of uranium for maintaining industrial processes that could just as well be powered by conventional means.


An easily understood article that explains the theory of the carbon-hydrogen-helium cycle for maintaining the release of energy from the sun and some stars. The difficulties encountered in attempting to make use of such a reaction on earth are explained.

32. General Electric Research Laboratory. Applications of atomic power. 1945, Pamphlet. 26p.

A collection of six addresses given by staff members of the research laboratory on topics such as the atomic nuclei, the mass-energy concept, fission, isotope separation, and the future of atomic power.


An outline of the Baruch plan for atomic energy control. It explains the three factors; production, sanctions, and inspection, that would be in the hands of an International Atomic Energy Authority, and tells why Russia objects to the plan.


This book consists of a series of the best articles and reports on various phases of the development of atomic power and the atomic bomb. The articles are all written by authorities in their special fields, and a 40-page bibliography of other articles about the atomic bomb is included.

A report of the possible outcomes of the use of atomic energy for industrial purposes showing some of the difficulties encountered and tells of work being done with the radioactive isotopes.


Ten color pictures taken at Bikini. They illustrate the tremendous power released by an atomic explosion and show quite well the radioactive cloud that accompanies the explosion. Very good photography.


The author considers the various aspects of control of atomic energy by the UNO with international inspection and concludes that there is no plan at present that will prevent the use of atomic power in warfare.


An evaluation of the probable uses of atomic power as predicted by men of science in view of present developments. This article is free of much of the sensationalism found in less authoritative articles.


The author points out the extensive use of caves and caverns during World War II and suggests that all civilization will be forced to live underground in the event of another war.


This is one of the first popularized articles that reported the possibility of
releasing atomic energy from U-235 and presents a fantastic picture of expected developments from the use of atomic power.


The author expresses the opinion that the basic facts about atomic energy are not too complicated for the general public to understand. Atomic energy shows and exhibits are planned to acquaint the people of the United States with the work being done with atomic energy.


This is an account of the problems facing the United States Atomic Energy Commission, and some of the work it is doing.


A news reporter explains why many of the first reports on the Bikini tests tend to depreciate the effects of the atomic bomb. He tells of the advance build-up and subsequent letdown when the explosion was observed from a distance.


An account of some of the more fantastic developments that may result from the release of atomic energy. This is an example of the type of article found in the less authoritative magazines.


The first beneficial results of atomic research have been new tools for medicine which promise cures for hitherto incurable diseases.
Progress and failures are pointed out, and a hopeful word about future research is given.


This is a very fine article on the structure of the atom and the atomic nucleus that is well illustrated and written in simple language.


This is one of the first articles to appear in a popular magazine following the announcement of the atomic bomb and illustrates the type of article written by people who were not authorities on the subject.


A discussion of the Atomic Energy Act is presented in which the author shows some of the problems encountered and compromises made in getting the bill through Congress.


A report of the isolation of neptunium and polonium, and the production of two new elements having atomic numbers 95 and 96. The article also gives a very simplified picture of the structure of an atomic nucleus.


The author expresses the need for study of atomic energy in the high school chemistry and physics classes.

This paper gives the scientific data that were available to the general public before the war with speculation as to how the bomb operated.


A scientist points out the futility of attempting to hide the facts of nature that went into the development of the atomic bomb. He suggests that the United States should follow a policy of security through achievement rather than concealment.


A description of early equipment used in atom smashing. It includes an attempt to collect lightning for this purpose and an impulse generator.


Tells why the older and somewhat weaker Van de Graaff is still used even though the cyclotron is capable of producing higher energies. It contains a very good description of both machines and their special uses.


This is the official government report on the development of the atomic bomb and serves as the guide for most other books that relate the story of the development. The report is too technical and involved for most high school pupils, but it is highly recommended for use by science teachers.


The role of air power in future warfare is considered in view of the atomic bomb. It is
shown that even with no further advances in aircraft design, it would be possible to carry atomic bombs to any point in the northern hemisphere by plane. A military point of view with future wars considered likely.


A short article that appeals for control of atomic power through international understanding and trust. It is an idealistic treatment of the subject of atomic control.


An accurate account of the circumstances that led to the use of the atomic bomb against Japan and the reasons for using it.


This book contains several experiments that would add to the interest in explaining some of the technical points about radioactivity and electrical charges.


A study of some problems involved in designing and operating an atomic pile for generating electricity. One possible plant is illustrated.


A news reporter’s impressions of what he saw and heard at Bikini. He explains why many of the observers were disappointed in the immediate effects of the bomb tests.

The author voices a strong appeal for control of atomic energy through inspection. Control must be so effective that no nation can manufacture atomic bombs without instant detection and punishment. He expresses the view that no future wars are possible in a world where atomic bombs will be used.


The political picture with respect to the development of atomic energy is drawn. The dilly-dallying that is hampering the development is pointed out, as well as the possible ill effects of such delay.


An illustrated article that shows the betatron in operation and shows in a vague fashion how the machine works and what is being done with it.


A pictorial account of the results of the Bikini tests showing the effect of radiation on the test animals and the fish at Bikini lagoon. The irresistible spread of radioactivity poisons that follows an underwater atomic explosion is regarded as one of the greatest hazards of the use of atomic bombs.


A report of the progress being made in applying atomic knowledge to practical problems with special emphasis upon the peacetime uses of atomic energy.

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A well known writer of scientific fiction looks into the future in this article and points out some of the outcomes of the release of atomic energy. He foresees either a series of implements of warfare that could destroy the world or a peace more luxurious than anything possible at present.