11-1981


George M. Turner
University of Kentucky

Click here to let us know how access to this document benefits you.

Follow this and additional works at: https://uknowledge.uky.edu/aees_reports

Part of the Bioresource and Agricultural Engineering Commons

Repository Citation
https://uknowledge.uky.edu/aees_reports/16

This Report is brought to you for free and open access by the Biosystems and Agricultural Engineering at UKnowledge. It has been accepted for inclusion in Agricultural Engineering Energy Series by an authorized administrator of UKnowledge. For more information, please contact UKnowledge@lsv.uky.edu.
Energy Resource Series for Youth and Adult Energy Programs

8. Nuclear Fusion

by

George M. Turner
Extension Specialist for Agricultural Engineering
Department of Agricultural Engineering
University of Kentucky
Lexington, Kentucky
The subject of nuclear energy can be divided into two parts, fission and fusion. The purpose of this publication is to describe the process of nuclear fusion.

Fusion of atomic nuclei offers tremendous possibility of energy. Since all forecasts point toward a need for more energy in this country, this method of energy production can provide a significant share.

At the present time we do not know for certain that energy from the fusion process will be scientifically and economically successful. It is certain that much research will continue to take place; if fusion can be achieved, the promise of the vast power possible will be worth the effort.

Before using this publication, it is strongly suggested that you study the first 14 pages of AEES-27, Nuclear Fission, since you will need to be familiar with the force fields prevalent in the nucleus in order to understand the fusion process.

This is the eighth publication in a 12-part energy resource series designed for the adult and student with a serious interest in the energy situation. Each publication in the series examines a different source of energy and considers the advantages and disadvantages associated with its use.

When necessary, diagrams and/or tables are used to clarify or elaborate upon information found in the text. Questions with answers are included at the end of each publication so that you can test what you have learned.

The author wishes to thank Joseph Taraba and Linda Bach of the Department of Agricultural Engineering, University of Kentucky, for reviewing the text.

The Energy Resource Series for Youth and Adult Energy Programs includes the following publications:

AEES-21   Energy Overview
AEES-22   Definitions
AEES-23   Oil and Gas
AEES-24   Coal
AEES-25   Solar
AEES-26   Wind
AEES-27   Nuclear Fission
AEES-28   Nuclear Fusion
AEES-29   Wood
AEES-30   Water
AEES-31   Geothermal
AEES-32   Alcohol
## Contents

<table>
<thead>
<tr>
<th>Topic</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Matter Into Energy</td>
<td>4</td>
</tr>
<tr>
<td>A Look at Hydrogen</td>
<td>5</td>
</tr>
<tr>
<td>Speeding Up the Particles</td>
<td>6</td>
</tr>
<tr>
<td>Fusing the Particles</td>
<td>7</td>
</tr>
<tr>
<td>Mini-Voltages</td>
<td>8</td>
</tr>
<tr>
<td>Fuel Reserves</td>
<td>8</td>
</tr>
<tr>
<td>Harnessing Fusion</td>
<td>8</td>
</tr>
<tr>
<td>The Need for Containers Without Walls</td>
<td>9</td>
</tr>
<tr>
<td>Designing To Fit the Theory</td>
<td>10</td>
</tr>
<tr>
<td>Continuous Fusion Method</td>
<td>10</td>
</tr>
<tr>
<td>Pulsed Fusion System</td>
<td>11</td>
</tr>
<tr>
<td>Other Methods</td>
<td>12</td>
</tr>
<tr>
<td>Environmental Effects</td>
<td>12</td>
</tr>
<tr>
<td>Fuel Sources</td>
<td>12</td>
</tr>
<tr>
<td>Questions</td>
<td>13</td>
</tr>
<tr>
<td>Answers</td>
<td>14</td>
</tr>
</tbody>
</table>
Energy Resource Series for Youth and Adult Energy Programs

8. Nuclear Fusion

Matter into Energy

In AEES-27, Nuclear Fission, the electrostatic and internucleon force fields were described. It was explained that the assembled nucleus has less mass than the sum of the individual nucleons making it up (Figure 1). This loss of mass is turned into energy according to the law $E = mc^2$ and is the source of nuclear energy. The curve in Figure 2 shows the average mass loss per nucleon for each element after recombining.

![Figure 1](image1.png)

**Fig. 1.**-Combining makes the difference. This illustration depicts what happens when separate nucleons, the particles that make up the nucleus, whether proton or neutrons, combine to form the nucleus of a more complex element. The arrows represent energy given off equal to the loss in mass. The mass of the four particles is greater while separate than after they have fused into one nucleus.

The mass loss is great (note the steep slope of the curve) for the lighter elements, that is, up to about Ca, atomic number 20; then the mass loss levels off for the medium elements, from about Fe to Pd. The graph indicates a more gradual loss per nucleon through the heavier elements up to Pu, atomic number 94.

![Figure 2](image2.png)

**Fig. 2.**—Loss of nucleon mass when separate nucleons combine to form the nucleus of various elements. The greater the loss per nucleon the greater the energy given up. The greater the vertical distance from one element to another, the greater the loss of mass per nucleon.

It is important to realize that two types of nuclear reactions are possible, occurring at opposite ends of this curve. In AEES-27, Nuclear Fission, the breakup or splitting of a large nucleus to form smaller ones was described. This is what happens on the right end of the curve. The subject of this publication is fusion or the combining of light nuclei into heavier or more complex ones. This happens on the left end of the curve. In both types of reactions the mass of the products is less than the mass of the original. It is this difference or loss of mass that provides the release of energy.
Notice on the right end of the curve that when a heavy nucleus is split, the end products, such as Kr and Ba from uranium, are at a higher vertical position on the curve than the original element, U. This indicates that each nucleon making up the final products has less mass than when the nucleons were all together in the large nucleus of uranium. This is illustrated in Figure 3A.

A Splitting of uranium can give krypton and barium

![U^{235}_{56} \rightarrow Kr^{84}_{36} + Ba^{138}_{56}]

234.95255 amu $\rightarrow$ 83.78025 amu + 137.30928 amu + Energy

234.95255 amu of assembled nucleus (by tests) -13.11258 amu of 13 neutrons expelled to space 221.83997 amu of original mass rejoined in Kr and Ba

Mass Difference = 221.83997 amu of original mass rejoined in Kr and Ba -221.08953 amu of the two new elements or products

0.75044

The 0.75044 amu loss of mass has been turned into energy.

B Four separate particles give helium.

1 - proton = 1.00728 amu as separate particle
1 - neutron = 1.00866 amu as separate particle
Total = 4.03188 amu as separate particle

Mass Difference = 4.03188 amu as separate particle -4.0026 amu of assembled nucleus

0.02928

The 0.02928 amu loss of mass has been turned into energy.

Fig. 3.—Products have less mass than the original whether from fission of uranium into krypton and barium (Fig. 3A) or fusion of hydrogen two into helium (Fig. 3B).

Theoretically, any of the elements from the heavy end of the curve would emit energy if split. In practice it has been found that only U^{235} and P^{244} will easily fission. These are the elements used as fuel in present nuclear energy plants. These fuels and their reactions are described in detail in AEES-27, Nuclear Fission.

In order for the lighter elements on the left end of curve to move upward on the curve they must combine, forming heavier elements. The combination being looked at most intensely is hydrogen (H) fusing to form helium (He). The process of fusion that takes place on the left end of the curve is illustrated in Figure 3B. The four particles (two protons and two neutrons) coming together to form helium have a greater mass as separate particles than after they are forced together to form the helium nucleus. As can be seen on the curve, a relatively great vertical distance lies between H and He. This indicates a much greater potential for energy release than on the flatter right end of the curve.

A Look at Hydrogen

Hydrogen exists with a single proton as its nucleus. Occasionally the proton will have a neutron attached. This is still the hydrogen element because of the single proton. However, it is twice as heavy because of the two particles in the nucleus. It is called hydrogen-two or deuterium with a capital D as the symbol. Sometimes the symbol H^2 is used while H^1 is used for hydrogen with the single proton as the nucleus. About one atom in each 6,000 hydrogen atoms is H^2.

Hydrogen also exists with two neutrons attached to the proton giving a total of three particles in the nucleus. This isotope is called tritium (T) or H^3. Tritium is extremely rare in nature but does occur in H^3 reactions for a very brief time. It can also be obtained by the bombardment of lithium (Li) with neutrons. These elements are illustrated in Figure 4.

Theoretically, to obtain helium from hydrogen, two hydrogen nuclei must be moving toward each other with high velocity. Their kinetic energy must be great enough to keep them moving toward each other despite the fact that their mutual positive charges are attempting to slow them down and push them apart. Two protons at two diameters apart extend a repulsive force of 0.13 pounds. If they come at each other with sufficient velocity and ample kinetic energy to overcome the electrostatic repulsion force field, the strong internucleon force fields interact and hold the two nuclei together. The necessary relative velocity has been calculated to be about 18 million mph.
Fig. 4.—The nucleons that take part in fusion reactions. The diagrams illustrate the number of protons and neutrons in each nucleus. The larger circle around each nucleus illustrates the electron orbits, one electron for each proton. The name beside each diagram is what the isotope is known by, followed by its symbol. The last figure gives the relative quantity of that isotope found in nature. The word trace means a very small fraction of 1 percent.

The strong nuclear force extends out about one nucleon diameter; thus, the two particles must be within a two-nucleon diameter of each other for these force fields to interact. After that, the force field is so strong (about 130 times the electrostatic force) that it pulls the particles together despite the repulsion of the two positive electric charges of the protons.

**Speeding Up the Particles**

The two positive particles can be shot toward each other at extremely high velocities, using a giant cyclotron. The result is shown in Figure 5.

Even at great distances the two positive charges begin to repel each other as indicated by the arrows in A. There is in effect, an electrostatic wall barrier between them. This repulsive force increases rapidly the closer the two protons get to each other as in B.

If the two particles have a high enough initial velocity their kinetic energy carries them against the repulsive force to a close enough distance that the strong nuclear force, Fn, surrounding each particle can come in contact and interact, pulling the particles together (C).

The internuclear force is approximately 130 times as strong as the electrostatic field. The electrostatic field continues to exert its repulsive force even when the two particles are being held together by the internuclear force. In D the two particles are completely together.

After the particles come together, their mass is less than when they were separate. This difference is emitted as energy. In this case, however, much more energy was required by the large cyclotron than was recovered by the nuclear reactions. This type interaction is only done in laboratories to demonstrate that fusion is possible.
Another way to get the two particles to approach each other at high velocities is to use high temperature. Hydrogen gas heated to an extremely high temperature causes the hydrogen atoms to vibrate so fast that some of them approach each other at the necessary velocity and fuse together. On earth, this temperature must be in excess of 100 million °C. This is practically impossible to realize; nothing on earth has a temperature that high. In the sun, where the enormous gravitational force at the center causes high pressures, the temperature from the fusion of hydrogen into helium is lower, at about 15 million °C. But on earth, we know of no possible way to provide such pressure and temperature.

On earth, the helium nucleus consists of two protons and two neutrons. Evidently the two neutrons provide extra connecting points for the internuclear force to hold on to, and they help hold the two protons together. In the sun with the aid of the high gravitational pressure, the two protons could possibly be held together without the aid of the neutrons.

Fusing the Particles

Taking a clue from this, scientists found that two H² nuclei could be fused together at a lower temperature. From this came hope of successful fusion of hydrogen. Figure 6 illustrates how H² would act in a similar way to H¹ which was illustrated in Figure 5.

The two H² nuclei are moved toward each other by some method, such as acceleration in a cyclotron or by use of a very high temperature (A). The electrostatic force field of each proton represented by the arrows has a repulsive effect on the two particles. This effect gets rapidly stronger, the closer the two get together (B).

The dashed line Fn around each particle represents the outer edge of the very strong internuclear force which is approximately 130 times as strong as the electrostatic force. If the two particles can get close enough together so that the strong nuclear force fields touch or interact, the two particles then snap together despite the repulsive force of the electrostatic field.

In C an important action probably takes place that makes H² fuse more easily than H¹. The two neutrons have a strong internuclear force field surrounding them, but no electrostatic field. If these two point toward each other the internuclear forces can touch sooner and keep the two protons farther apart; thus, their repulsive force is less because of greater distance. The four particles probably juggle around and finally settle into the closest, snuggest position possible as shown in D.

Theoretically, H¹ would unite at still a lower temperature, but H³ is radioactive. Being quite unstable, the extra neutron stays connected for a very brief time. Therefore, H³ enters into the reaction only while it is going on and does not stand by waiting to help out the situation.

Researchers have found that the reactions between hydrogen nuclei to form helium take place in the following ways (Figure 7):

1. \( H² + H² \rightarrow He³ + n \) @ 3.2 MeV
2. \( H² + H² \rightarrow H³ + H \) @ 4 MeV
3. \( H² + H³ \rightarrow He⁴ + n \) @ 17.6 MeV

Fig. 7.—The nuclear reactions in the fusion process. Scientists have fairly well determined that these three reactions dominate the fusion process. The diagram beneath each element in each reaction helps keep track of what each element looks like.
These two reactions take place at about an equal rate when a volume of H₂ gas is heated to extremely high temperatures. The random vibrations can cause some fusion to take place. The number value at the right of each reaction indicates the amount of energy given because of the loss of mass as fusion takes place.

**Mini-Voltages**

The term MeV means million electron volts. This is used by scientists to describe nuclear phenomena. Chemical reactions averages about 1 eV for each individual occurrence of the reaction. Chemical reactions however, occur with electrons shifting from one atom to another only under the influence of the electrostatic force.

The nuclear reactions occur under the strong internuclear force field and involve hundreds of times the energy of chemical changes. To help visualize the energy defined by the MeV term we use the following equalities:

\[ 1 \text{ eV} = 1.6 \times 10^{-19} \text{ J} \]
\[ 1 \text{ MeV} = 1.6 \times 10^{-13} \text{ J} \]
\[ 1 \text{ J} = 10^{-3} \text{ Btu} \]
\[ 1 \text{ MeV} = 1.6 \times 10^{-10} \text{ Btu} \]
\[ 1 \text{ MeV} = 0.00000000016 \text{ Btu} \]

The quantity of energy in 1 MeV (one million electron volts) is quite small. It would take 16 billion MeV to produce one Btu which is about the heat one wooden kitchen match produces, chemically, when allowed to burn up completely.

In the two H₂ reactions presented in Figure 7, only one results in producing H³. Tritium immediately reacts with any available H², as follows (from Figure 7):

\[ \text{H}_2 + \text{H}_3 \rightarrow \text{He}^4 + n @ 17.6 \text{ MeV} \]

This reaction shows what scientists have predicted; tritium will combine to form helium and produce great amounts of energy.

The total energy produced from these three reactions, which all take place in a very short time, is 24.8 MeV. Calculations show that 1 gram of H² could emit 5.6 x 10⁶ calories or 2.2 x 10⁸ Btu. One gallon of water contains about one-eighth gram of H²; if all these could be gathered together and made to fuse they would emit 2.8 x 10⁸ Btu of energy. One gallon of gasoline provides about 124,000 Btu when burned. Therefore, the energy from the H² nuclei in a gallon of water equals that in 224 gallons of gasoline.

We should also remember that the splitting, or fission, of one uranium nucleus releases about 200 MeV. This is several times what one nuclear fusion reaction releases, especially from reactions 1 and 2 only. Because the fusion nuclei are lighter there are many more of them per gram of fuel; therefore, much more energy can be obtained from 1 gram of hydrogen than from 1 gram of uranium.

**Fuel Reserves**

The fuel supply of uranium is limited or finite for a fission reaction. However, the fusion process, based on hydrogen, would have an almost unlimited supply. Deuterium can be easily obtained from ocean water, and there are billions and billions of tons available.

Even if the fusion system devised requires lithium to trigger or support the reaction, this is not a great handicap since this element exists in fairly large amounts and is not overly expensive. From an economic standpoint, the fuel for fusion presents few problems.

**Harnessing Fusion**

The safety of plant operations and the fact that there are few radioactive byproducts enhance the fusion process as a source of energy. The enormous problem arises in being able to supply the extremely high temperature necessary to trigger the fusion of the light hydrogen nuclei. Here are some of the ways scientists and engineers are approaching the problem.

One method that could be put to use in 10 years or less, is to capture energy from hydrogen fusion. This method involves the use of small underground thermonuclear devices (hydrogen bombs). The earth absorbs the heat of the reaction and holds it for quite a long time compared to atmospheric reactions where the energy dissipates quickly. Water can be forced to circulate through the heated portion of the earth and be converted to steam (similar to geothermal systems) to drive above-ground steam turbines. When the earth has cooled somewhat, another device is triggered so that a relatively high and even level of temperature can be maintained in that portion of earth.

This method however, has the drawback of needing a fission device to furnish the heat to set off the hydrogen device. This means that the critical uranium is still needed. This method also receives a lot of resistance from some groups because of the potential danger that these underground explosions could cause unforeseen damage.
Also, remember that a particle accelerator or cyclotron can be used to speed hydrogen nuclei toward each other and fuse them. But this particular method requires much greater inputs of energy than can be recovered. So, there are at least two methods that will work but which have unacceptable drawbacks.

Another method which is presently receiving the major emphasis is the use of extremely high temperature, confined, ionized hydrogen gases (plasma). A plasma, in this case, can be defined as a mixture of hydrogen nuclei and an equal number of electrons with each particle containing so much kinetic energy that the electrons do not stay attached to any proton in an orbit. In the plasma, the number of positive ions equals the negative ions with the overall result that the plasma is electrostatically neutral. It is estimated that if H₂ is the gas involved, a temperature of at least 100 million °C will be required. This is a much higher temperature than the interior of the sun, 15 million °C, where the reaction readily takes place. The sun however, has the tremendous pressure from gravity to aid it.

To form a plasma condition in the first place, the hydrogen atoms can be ionized by a high voltage similar to a fluorescent light.

### The Need for Containers Without Walls

In this state the nuclei (proton and neutron) as well as the electrons are in extremely rapid rates of vibrations due to the high energy provided by the temperature level. Any type physical vessel having solid walls would cool the outer fringes of the plasma quickly, which in turn would conduct the heat away from the remaining plasma. It may seem that the extremely high temperature of the plasma would melt any physical vessel attempting to contain it. But the gas is very thin and contains relatively little total heat. The problem then is not that containers are in danger of being destroyed but that as energy is taken from the plasma, the temperature drops, and the experiment fails. Attempts are being made to contain the plasma with vessels other than the conventional ones.

The charged particles in the plasma can be controlled or forced to move in a desired direction by use of magnetic fields. The density of the plasma (10¹⁸ nuclei/cm³) contained is approximately 1/30,000 of normal room air density (3 x 10¹⁸ molecules/cm³) but because of the high temperature and rate of particle vibration the pressure is about 200 pounds per square inch.

In an ordinary closed vessel containing a heated gas, the atoms or molecules move in random, straight lines, until they collide with other particles or the wall of the container. Then they rebound, moving in random, straight lines until striking another object.

Ionized particles in a plasma, moving under the influences of a magnetic field, are guided in a different manner. If the magnetic lines of force penetrate the plasma, the positively charged particles (protons or nucleus) will, while moving, circle a magnetic-force line. The negative particles circle in the opposite direction. This is illustrated in Figure 8. The charged particles are forced to follow the lines of force and are thus prevented from escaping the circle representing the wall of a container. As long as the magnetic lines of force remain, there is no need for the container wall. Note in the end view that the positive and negative charges rotate in opposite directions.

The diameter of the motion that a particle has around a magnetic line of force depends upon the strength of the magnetic line of force and the mass of the particle. Since protons are some 1,800 times...
as massive as the electron, the proton makes a larger circle around a magnetic force line than does the electron. This also is illustrated in the end view of Figure 8.

Particles moving diagonally across the cylinder vessel when the magnetic field is applied are attracted to the nearest line of force and travel down the tube in a spiral motion. However, the particles moving directly across the tube when the magnetic field is applied, are captured by a magnetic line of force and circle it, without moving up or down the cylinder. Also, particles moving directly along the cylinder, with no cross motion at all, continue this motion, between lines of force, and do not circle at all.

Thus, even with a magnetic field penetrating a plasma there can be random motion and most importantly, the possible collision of particles. This is necessary in order to have fusion. At the same time, the particles are confined to the magnetic line of force. This theory is the basis of research in the realm of magnetic confinement.

Designing To Fit the Theory

The physical method employed in supplying the magnetic field is to use electric conducting wires surrounding the container. The way these wires are wound produces various shaped magnetic fields, that is, various shapes and movements of the ion particles. Three methods are shown in Figure 9. In studying this figure, remember that an electric current always induces a magnetic field at right angles to it.

In the cylinder type container, the electricity-conducting wires are wrapped around the container (A). The magnetic lines of force are at right angles to the conducting wire, and thus are parallel to the cylinder. The conducting wires are wound more closely at the end of the cylinder providing a stronger magnetic field that repels the particles and keeps them between the ends. This is called the reflective or mirror type containment.

In B, a doughnut-type (torus) container, the conducting wires are wound around the closed container. The magnetic lines of force move perpendicular to these wires, and thus form in circles concentric with the torus.

In C, also a torus type container, the conducting wires run concentric with the torus on the surface of the container. The magnetic lines then form closed circles within the torus. Note that B and C are wound opposite to each other. Therefore, the magnetic fields are oriented opposite to each other inside the torus. In either case charged particles can be kept from touching the sides of the container. A and B are of the closed type, while A is an open type.

Even though we are not absolutely sure that energy from controlled fusion will ever be practical, many scientists and engineers are confident enough that they are making plans of the entire systems.

Continuous Fusion Method

A system utilizing the heat from a fusion reaction is illustrated in Figure 10. This is a continuous method. Once the system starts and fuel is furnished, it continues to operate, much like a fire-place, jet engine, or gas-fired boiler. This is unlike pulse systems, to be described later, which are like the internal combustion engine that takes in a charge of fuel, ignites it, uses the power, then takes in a new charge and has to ignite it again.
In the continuous system of Figure 10, a plasma is magnetically contained at the center of a vessel. The fusion of hydrogen nuclei into helium produces vast amounts of heat, some of which helps to keep the plasma at the extremely high temperatures necessary for continuous operation. Surrounding this magnetically contained plasma is a thick layer of lithium kept molten by the high temperatures. Inside the lithium are heat exchangers in which potassium is circulated. The potassium is vaporized in the heat exchangers and drives a turbine (A) connected to a generator (G). The potassium exhaust, still at a very high temperature, goes to a condenser (B), actually a heat exchanger, and is returned to the lithium heat source again by a pump (C). The condenser (B) heats water to steam which in turn drives a conventional steam turbine (D) connected to a generator (G). The steam is condensed in E by air or a local water source and is pumped (F) to the heat exchanger (B) for reheating to steam. The total amount of power generated by this entire system is controlled by the amount of new fuel (hydrogen) injected.

The overall effect is that this system has the possibility of recovering at least 50 percent of the heat generated by the fusion process and turning it into electrical energy. Present-day coal fired plants attain an efficiency of 35 to 40 percent. If the calculated efficiency can be achieved, the fusion plant would inflict less heat stress on the surrounding environment because less waste heat would need to be dissipated to the air or to nearby water.

Pulsed Fusion System

There is a pulsing system contemplated for utilizing heat from a fusion reaction. This is illustrated in Figure 11. In this system a very tiny, frozen pellet of fuel, $H_2 + H_3$, shown at (A), is injected (B) toward the center of the spherical chamber. When it reaches the center, lasers (C) discharge simultaneously. (There can be more than just the three shown, with all equally spaced.) The lasers heat the outer surface of the pellet to a depth of a nucleus or two, which is sufficient to cause fusion of adjacent nuclei. The energy given off in their reactions heats the entire pellet so rapidly that the nuclei cannot move away as fast as the heat builds up; therefore, fusing easily takes place in the interior of the pellet. After a short time, the heat build-up literally blows the pellet apart but only after a very high percentage of all nuclei combine or fuse.

Between the linings of the shell of the vessel is a medium, such as lithium. The heat keeps it in a molten state. A heat exchanger is placed in this medium containing another medium, such as potassium salt or helium gas which is circulated through a condenser (E) by pump (G) where steam
is formed to turn turbine (H) connected to the generator (I). The condenser (J) is cooled by air or a local water source. After each pellet has reacted, a new one is injected, ignited, and the cycle repeated. The amount of energy generated is controlled by how many pellets are injected per unit of time.

Other Methods

Considerable research is going on now in an attempt to design and develop lasers with enough energy to ignite the fuel pellets' surface nuclei. It may be that photon radiation above the frequency of light will have to be employed to get several hundred times more energy. These may be called XASERS, if something like X rays is used; or, GASERS if gamma ray frequencies are used.

Another possible method that captures the imagination of designers is the direct conversion of the fusion process into electricity without going through the turbine-generator equipment. This is illustrated in Figure 12 where the right-hand half of a magnetically-contained, cylindrically shaped plasma (A) is shown. The ionized particles are allowed to escape from the end (B) as their velocity is increased by the heat of fusion. The ring (C) carries a slight positive charge which collects the free electrons.

Fig. 12.—A scheme for the direct conversion of the fusion process into electricity.

The positively charged nuclei of helium, being much heavier, are deflected less and are attached to the slightly negatively charged collector rings (D). The result is a high voltage DC current output. Appropriate equipment (E) can be added to adjust the voltage level and to provide AC current.

The main reason for the interest in a method such as this is the high efficiency possible. It is possible to convert up to 90 percent of the fusion energy into electrical energy. If such a system can be devised, the side effects on the environment can be lessened because much less wasted heat will have to be disposed of.

Environmental Effects

The effect of any one of the processes for developing energy from fusion should not have any greater impact on the environment than present fossil fuel systems producing the same amount of electric power. The impact could be much less if engineers can develop operating designs that approach the efficiencies which the theory promises.

There is no danger of giant thermonuclear explosion since the quantity of potential fuel is so small. The only radioactive material connected with the process is the tritium created. This occurs only during the reaction, and it immediately goes into further combination to form helium.

Fuel Sources

Since the effect on the environment can be at an acceptable level by the proposed operating systems, another big plus factor is the source of the fuel. Unlike the fossil fuel and the uranium situation, the H2 fuel supply available is enormous. Even with only one atom in 6,000-7,000 atoms in seawater, the quantity is very large (10^{13} tons), and the cost of extracting H2 from the waters of oceans is not prohibitive. It is quite likely, if the fusion process is successfully achieved, that we will see these plants near the sea or even on floating platforms (engineers have elaborate proposals) to take advantage of waste heat disposition and acquisition of fuel. These power plants could also produce hydrogen gas by electrolysis of seawater and move this gas by pipeline to consumers on land to take the place of depleted natural gas.

It is because of this vast fuel supply that the fusion process commands so much attention today. Certainly this area will be one to continually study for current innovations and developments.
Questions

To stimulate thought and greater understanding, answer these questions with the best word(s) to make a true statement. Refer to the material when necessary.

1. The combining of the nucleus of two hydrogen atoms emits energy because of ____________________________

2. The combining of nuclei is called ____________________________

3. The splitting up of a heavy, complex nucleus is called ____________________________

4. Which process, fission or fusion, gives the greatest amount of energy per reaction? ____________________________

5. Give the reason for your answer to question number 4. ____________________________

6. What keeps regular hydrogen nuclei from uniting readily under conditions here on earth? ____________________________

7. What must be done to overcome the conditions in question number 6? ____________________________

8. Hydrogen can exist in three forms, H¹, H² and H³. Which of these unites the easiest? ____________________________

9. Which of the three hydrogen forms is radioactive? ____________________________

10. Why is H² or deuterium, the most practical answer for the fusion process? ____________________________

11. Does H² exist in large quantities? (Yes or No) ______

12. The H² in one gallon of water theoretically can release as much energy as how many gallons of gasoline? ______

13. Briefly describe one method that could be used in the near future that takes advantage of fusion. ____________________________

14. What technical obstacle stands in the way of practical fusion systems today? ____________________________

15. Why can't the plasma, at extremely high temperatures, be kept in steel-insulated vessels? ____________________________

16. What method of containment is now being researched? ____________________________

17. What three types or methods are being considered as energy producers? ____________________________

18. What system theoretically could produce power with the greatest efficiency? ____________________________
19. Do proposed fusion designs cause more detrimental impact on the environment than fossil fuel plants? (Yes or No) ______

20. What system of triggering each cycle is proposed in the pulsed design? ________________________

21. Does fusion power offer relief to natural gas consumers? (Yes or No) ______

22. What is the process called when hydrogen gas is obtained from seawater? ________________________

23. Is there danger of a gigantic explosion of a fusion power plant? (Yes or No) ______

24. Give your reason for the answer to question number 23. ________________________

Answers

1. loss of mass of each of the nucleons
2. fusion
3. fission
4. fission
5. The uranium nucleus is so much more massive.
6. Positive charges repel.
7. the two protons be given extreme velocity toward each other
8. $\text{H}_3$
9. $\text{H}_3$
10. more abundant than $\text{H}_3$ and not radioactive
11. yes (many, many tons in seawater)
12. 224
13. underground absorption of heat from hydrogen explosion devices
14. the extreme high temperature needed
15. The steel sides cool the plasma and stop the reaction.
16. magnetic
17. cylinder, doughnut, torus (Figure 9)
18. direct conversion from cylinder type containment
19. no
20. laser beams
21. yes
22. electrolysis
23. no
24. There is too little quantity of fuel involved.