FUSION

Nature's Fundamental Energy Source

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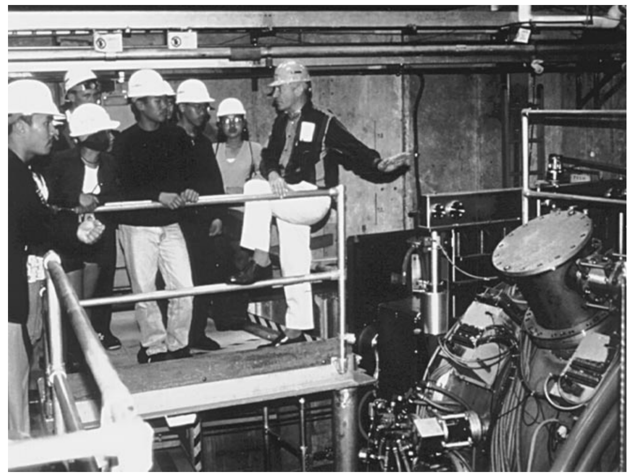
Preface

This workbook is part of an educational outreach program sponsored by the General Atomics Fusion Group and the U.S. Department of Energy. The overall program consists of a pre-tour video to be shown in the classroom, a half-day educational tour of the DIII–D magnetic fusion research facility located at General Atomics in San Diego, California, and post-tour materials, of which this workbook is a major part. This workbook contains an overview of the fusion process and questions related to the tour's six educational stations providing work assignments for students after they leave the site. The overall program was developed as a collaborative effort between fusion scientists and engineers at Generals Atomics and local San Diego school teachers.



In developing this fusion tour package, the fusion educational team identified phenomena which are utilized in fusion energy research and which are important to a science curriculum. The tour focuses on connecting science principles taught in the classroom with phenomena used in industrial research. Buses can be provided on a limited basis to transport local students for the half-day tour.

The tour begins with an initial presentation on the fusion process. Following this presentation, the students are split into small groups and rotate through six educational stations. The themes of the educational stations are:

- **DIII–D Tokamak & Fusion Power**
- **Plasma: the Fourth State of Matter**
- **Electromagnetic Spectrum**
- **Radiation, Radioactivity & Risk Assessment**
- **Data Acquisition and Control**
- **Engineering Analysis, Design and Manufacturing**

A scientist or engineer at each station explains the phenomena to the students. Demonstrations and hands on equipment are part of most exhibits. Finally, the students are reassembled for a final question and answer session.

An overview of the fusion process is contained in the first section. This is followed by six workbook sections containing questions related to fusion in general and the subjects covered in the DIII–D tour. Finally, a glossary of terms is presented.

FUSION

Nature's Fundamental Energy Source

Fusion energy, the power source of the stars, represents a potentially unlimited source of energy for humanity. For billions of years nature has used fusion in stars as its preferred method to produce energy.

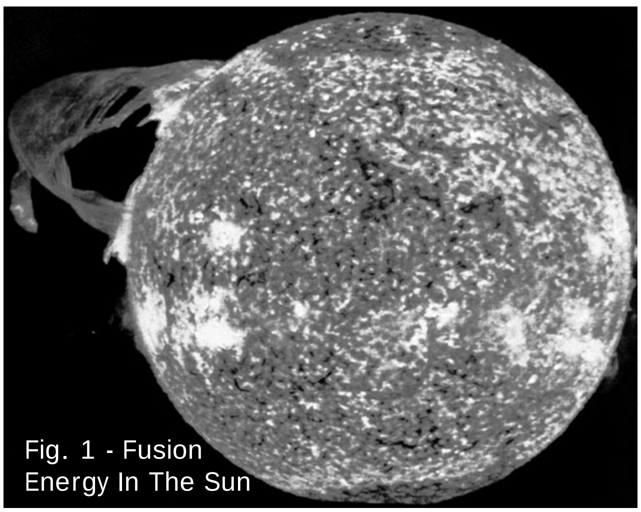


Fig. 1 - Fusion Energy In The Sun

Fusion involves the interaction of matter and energy, and the scope of fusion ranges from tiny subatomic particles to red super-giant stars. The last half century has seen scientists from all over the world working together to harness and control the sun's fusion process here on earth.

Humanity owes its existence to the sun's fusion engine. Fossil fuel deposits, the life blood of our civilization, form when plants capture and store the sun's energy.

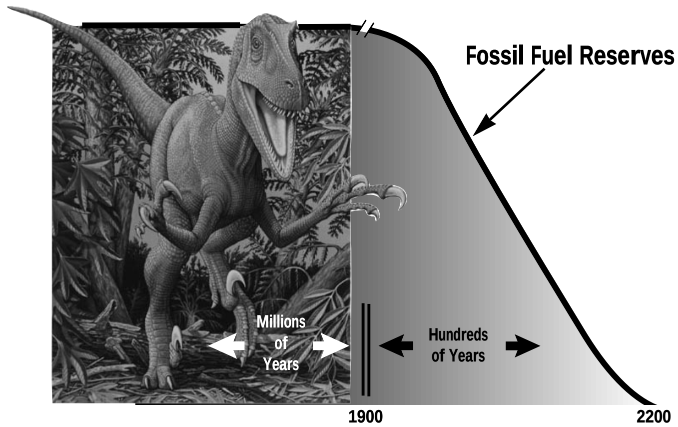


Fig. 2 - Fossil reserves are rapidly being depleted.
Dinosaur painting by John Klausmeyer. Courtesy of U. of Michigan Museum of Natural History.

Within a few centuries mankind will have depleted fuels that took millions of years to create (Fig. 2). Scientists are trying to replace this energy source with one destined to outlast our civilization: **fusion**.

What Exactly is Fusion?

In a fusion reaction two light atoms combine, or fuse to form a heavier atom and release energy (Fig. 3). The fusion process accounts for the creation of all

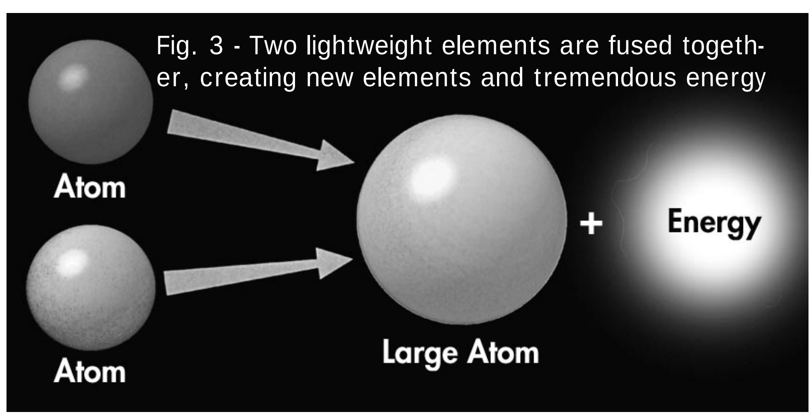


Fig. 3 - Two lightweight elements are fused together, creating new elements and tremendous energy

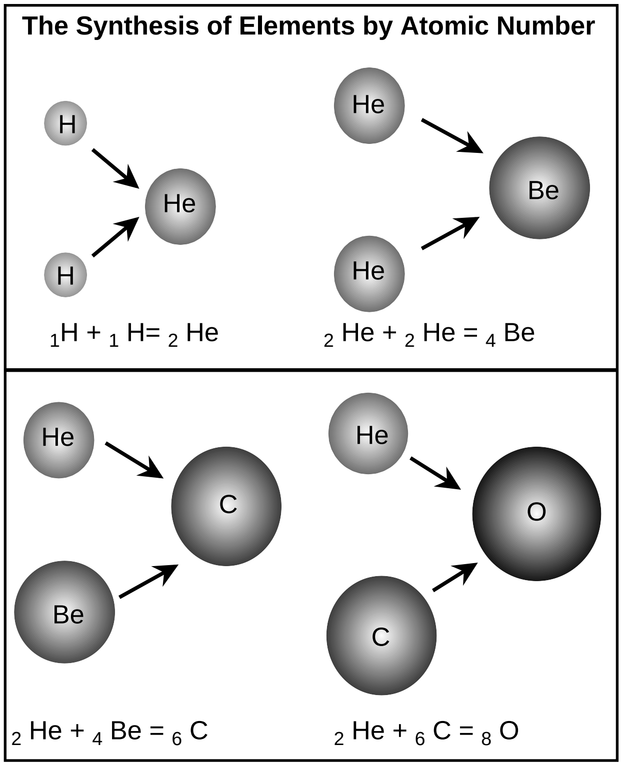


Fig. 4 – New elements created during the fusion process.

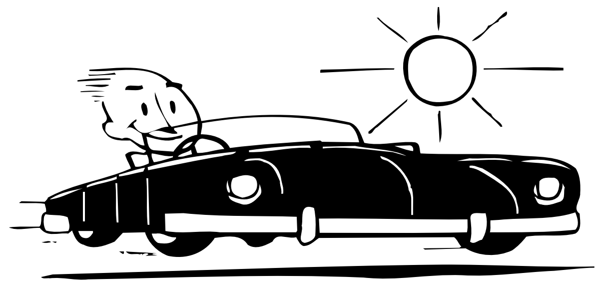
elements heavier than hydrogen in the universe (Fig. 4). In addition, during the fusion reaction a small amount of matter is “lost,” that is, converted into energy. This energy powers the thermonuclear engines of the sun and stars, and provides the energy for almost all life on earth. **How can the energy source of the stars help us on earth?**

There’s No Energy Crisis Now, But ....

With relatively stable gas, oil, and electricity prices today, there is no longer much public concern about an energy crisis. However, in the early part of the next century at the present rate of consumption the earth’s oil gauge will start to approach empty. Natural gas reserves will hold out for about another century.

Our tremendous coal deposits will last several more centuries, but burning coal will come at a high environmental cost.

Since 1990, over 1.3 billion metric tons per year of carbon dioxide have poured into the atmosphere in the United States alone as a result of the combustion of coal and other fossil fuels.



Existing nuclear power stations are able to provide about 20% of the U.S. electricity needs. However, no new nuclear power plants are planned because of the perceived high plant cost, safety concerns and waste disposal problems.

Alternative sources of electrical energy generation such as solar, geothermal, and wind (renewable resources) are being developed, but they are still expected to supply less than 15% of the nation’s electricity needs well into the next century. Fusion is a strong candidate to produce the enormous amount of electricity needed for the future in the world’s developing countries as well as the U.S.

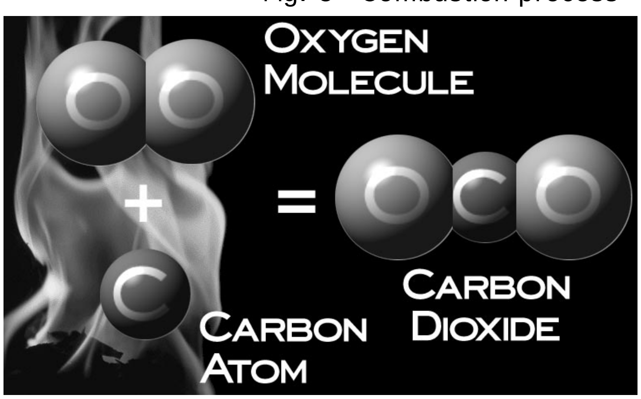
Combustion, Fission and Fusion: How do they differ?

While all these reactions produce heat, they differ fundamentally in their atomic ingredients. Combustion is a **chemical reaction** and involves the joining or separating of atoms to form **molecules**.

Atoms are made up of a heavy, compact, positively charged central core called the **nucleus** and a number of light, negatively charged particles called **electrons**. The fast moving electrons whirl around the nucleus and form a cloud that completely surrounds the nucleus and electrically balances the atom.

In the combustion process **binding energy** is released as atoms are electrically joined through the sharing of their outer most electrons. The resulting molecule is at a lower energy state than the reacting atoms. The nucleus of each atom is not changed in the reaction. The combustion of coal is a good example of the chemical reaction in which carbon (C) and oxygen (O_2) combine to form carbon dioxide (CO_2) and excess energy in the form of heat (Fig. 5).

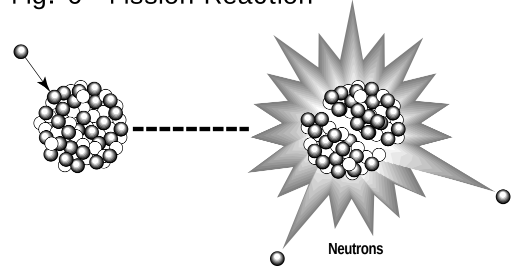
Fig. 5 - Combustion process



Fission and fusion are **nuclear reactions** and involve changes in the foundation of the nucleus. The nucleus is made up of positively charged **protons** and electrically neutral **neutrons**. During a nuclear reaction the number of these particles within the nucleus changes, sometimes creating different elements in the process.

In the **fission** process, a large atom is split into smaller atoms releasing energy from the nucleus (Fig. 6). Fission occurs spontaneously in many **radioactive** materials or is induced by chain reactions, like those occurring in today's nuclear power

Fig. 6 - Fission Reaction



plants. The heavy element **uranium (U)** is the primary fuel used in fission reactors. High energy neutrons circulating in the reactor core strike the nucleus of uranium**,** splitting it apart to form lighter elements and releasing energy and neutrons to maintain the chain reaction.

Fusion is the reverse of fission in that two light atoms are joined or fused to form a heavier element (Fig. 7) . Fusion involves the lightest elements in the **periodic table**. **Hydrogen (H)**, the lightest of all elements, is the raw material used in the sun's fusion engine. Under intense temperature and pressure within our stars, hydrogen atoms fuse to form **helium (He)**, the second lightest of all

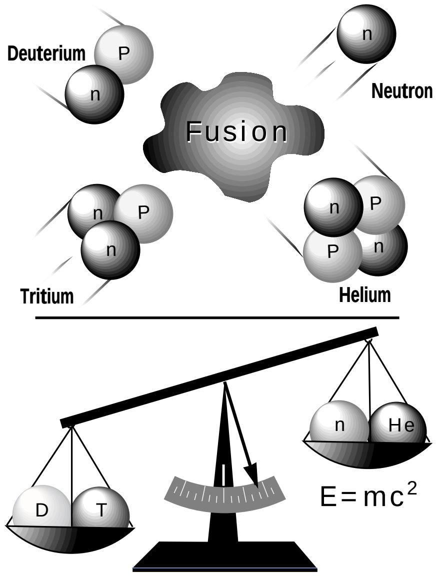


Fig. 7 - After the fusion reaction, the products have less mass than the original reactants. The "lost" mass has been converted into energy.

elements. On earth scientists hope to use a mixture of more reactive hydrogen **isotopes**: **deuterium (D)** and **tritium (T)**.

Like hydrogen, these isotopes have a single proton in their nucleus. Deuterium has an extra neutron and tritium has two extra neutrons. In the D-T reaction, helium and a neutron are formed with the excess energy released as kinetic motion of the resulting particles.

For almost a half a century, researchers around the world have studied methods to control fusion reactions. There was early optimism that taming fusion would be as easy as controlling fission (splitting of the atom). This early optimism soon gave way to the sobering reality that controlling fusion would be accomplished only after many years of painstaking research, technological advancements, and engineering breakthroughs.

Reaction		Output Energy	Typical Fusion Temperature
Fuel	Product	(keV)	(millions of °K)
D + T	^{4}He + n	17,600	~50
D + ^{3}He	^{4}He + p	18,300	350
D + D	^{3}He + n	3,250	400
	T + H	4,000	400

Fig. 8 - On earth, different fusion fuel mixtures ignite at different temperatures with differing output energies.

Why the Difficulties in Achieving Fusion?

The answer lies within the atom itself. Practically all physical matter on earth is composed of one of the three ‘common’ states of matter — *solid, liquid, or gas*. In these states electrons revolve around nuclei composed of neutrons and protons. In the rest of the universe, however, by far the most common state of matter is **plasma: the fourth state of matter**. Within a plasma, electrons are

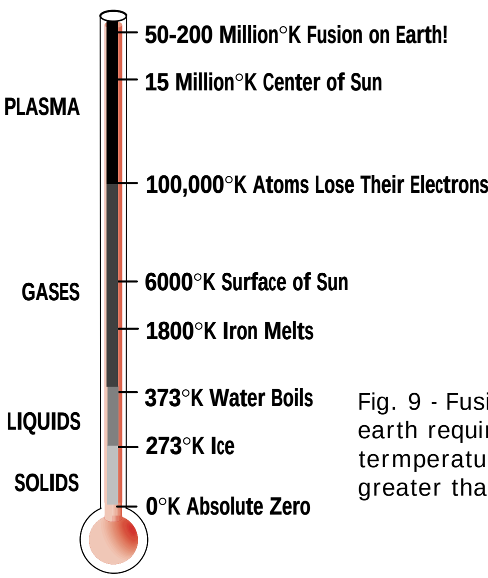
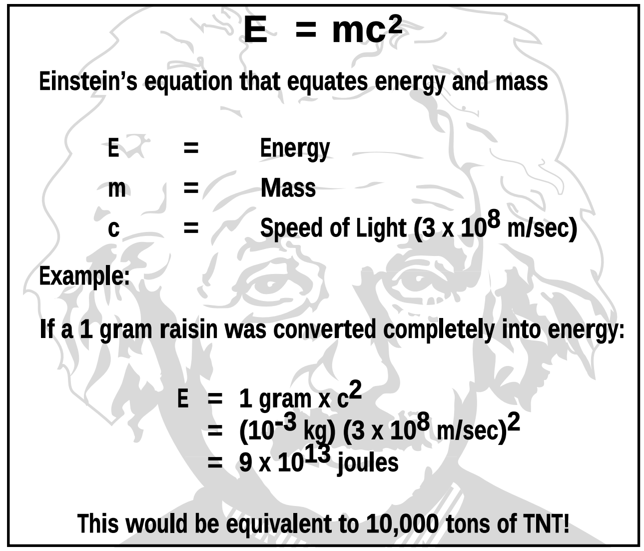


Fig. 9 - Fusion on earth requires termperatures greater than the sun

free to move independent of the nucleus and the gas is essentially a sea of charged particles. More than 99% of our visible universe is in a plasma state.

Producing plasmas on earth is a difficult proposition; it takes temperatures in excess of 10 thousand degrees **Kelvin** (10,000 K). The fusion process requires even higher temperatures. For instance, the sun’s plasma is at temperatures in



$E = mc^2$

Einstein’s equation that equates energy and mass

E	**=**	**Energy**
m	**=**	**Mass**
c	**=**	**Speed of Light (3×10^8 m/sec)**

Example:

If a 1 gram raisin was converted completely into energy:

$$E = 1 \text{ gram} \times c^2 = (10^{-3} \text{ kg})(3 \times 10^8 \text{ m/sec})^2 = 9 \times 10^{13} \text{ joules}$$

This would be equivalent to 10,000 tons of TNT!

Fig. 10 - As Einstein's equation indicates, the small amount of matter "lost" during a fusion reaction is converted into an enormous amount of energy.

excess of 10 million Kelvin and is sufficient to cause the positively charged hydrogen nuclei to overcome their natural electric repulsion and, through a series of steps, fuse together to form helium. Without the extremely high density of the sun, temperatures almost 10 times hotter or 50 to 200 million Kelvin are needed to sustain the fusion reaction on earth.

Where Does Fusion Energy Come From?

Like the fission, the fusion reaction converts mass to energy. In the deuterium-tritium reaction, mass of the resulting helium and neutron are less than the initial reactants. The mass loss is only 38 parts out of 10,000; however, as Einstein’s famous equation $E=mc^2$ indicates, even a small amount of matter can produce enormous amounts of energy (Fig 10).

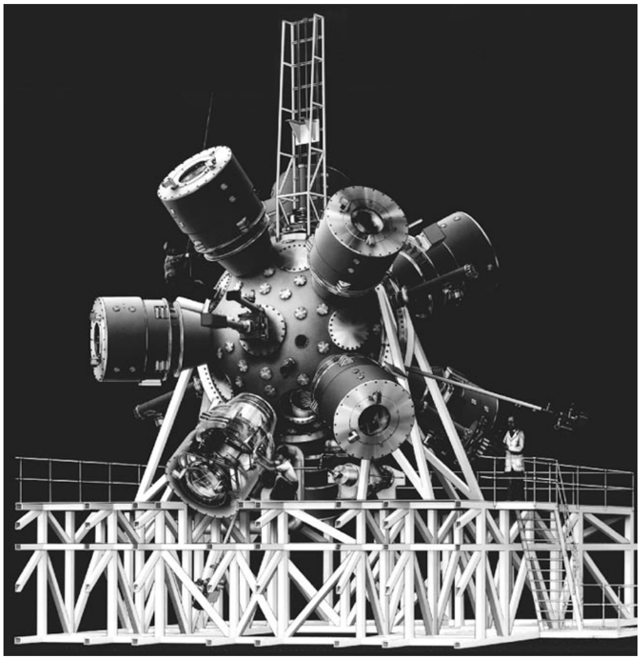
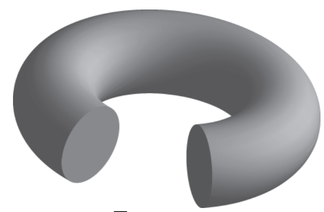


Fig. 11 -100 trillion watts of power from the NOVA laser are focused on a fuel pellet the size of a grain of sand in this chamber.

The Sun Works But How Can We Make Fusion Here on Earth?

Unlike the car in "*Back to the Future"*, we can't simply add trash to a souped-up DeLorean and expect fusion power to work. In the natural fusion process of the stars, the plasma is ignited by high temperature and contained in the vacuum of space by the gravitational force of their own huge mass, known as **gravitational confinement.** Here on earth, however, two different methods are being pursued to contain such high temperature plasmas: **inertial confinement** and **magnetic confinement**. The inertial confinement concept uses intense energy beams such as lasers to compress and heat tiny pellets of frozen hydrogen so quickly that fusion occurs before the atoms can fly apart (Fig. 11). Temperatures in excess of 50 million K and densities 20 times that of lead are needed to achieve fusion using this concept.

One of the most promising approaches for fusion power is the magnetic confinement concept. Strong magnetic fields act like a magnetic bottle to hold the ionized (charged) nuclei together and away from the vessel wall as they are heated to fusion temperatures. A Russian design called a **tokamak** has proved particularly well suited for containing a fusion reaction (Fig. 12). A tokamak is in the shape of a torus, which looks like a doughnut.



Torus

Deuterium and tritium are introduced into the hollow torus and ionized into a plasma using an electrical discharge. The plasma is heated to fusion temperatures using neutral beams, lasers,

Fig. 12 - Inside the DIII-D Tokamak at General Atomics in San Diego, California.

microwaves, and resistive heating. The physical characteristics of a plasma — it is charged and conducts electricity — allow it to be constrained magnetically. Since no physical material can with stand the 50–200 million Kelvin fireball of a fusion reaction, powerful magnetic fields generated by current carrying coils surrounding the torus are used to keep the plasma in place. A 50/50 mixture of deuterium and tritium (DT) is used since it will ignite at the lowest temperatures and produce the most energy (Fig. 8 – pg. 7).

If Fusion Is So Hard To Produce Why Do It?

Despite the technological hurdles on the road to fusion energy, many aspects of fusion remain extremely appealing: 1) fuel availability and accessibility, 2) energy density of the fuel, and 3) safety aspects.

The fuels of fusion, deuterium and tritium are essentially inexhaustible. Deuterium can be easily extracted from sea water where it comprises one out of approximately 6500 hydrogen atoms. Tritium can be produced as a by product of the fusion reaction by combining an energetic neutron with an abundant light metal, **lithium.** Unlike other natural resources, these fuels are available world wide and no one country can control their supply.

The amount of fuel necessary to power a fusion device is small compared to the amount of fuel used in other energy devices. One liter (~1.1 quart) of deuterium contains approximately the same amount of energy as 6600 tons of coal. It is the most compact fuel source known to man (Fig. 13).

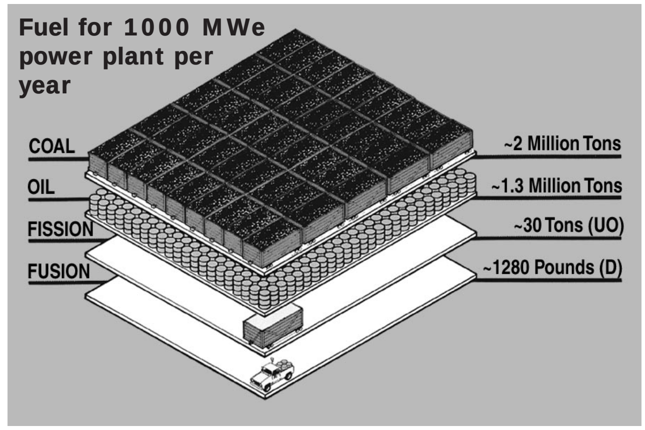


Fig. 13 - Fusion fuel is an extremely compact energy source

The physics of a fusion device also make it inherently safer than a fission reactor. If something goes wrong in a fusion device, the plasma just cools down and the reaction stops. Chernobyl type accidents are not possible with a fusion power plant.

The waste gas of the fusion reaction is helium, an inert gas used to fill balloons. Dealing with the radioactive waste from fission-powered nuclear plants has proved difficult due to the high level of radiation and long isotope **half-life** — the time it takes for half the radioactivity to decay. While radioactivity is produced in the process of stopping energetic fusion products, much lower levels are produced. Only the reactor walls become radioactive and the material half life is many orders-of-magnitude lower than fission products. Utilization of special materials in the future may reduce this level even further.

What is the World Doing to Meet the Fusion Challenge?

Meeting the challenge of fusion has been the task of over a dozen tokamak research facilities worldwide, including the JT-60U in Japan, the ASDEX-U in Germany, T-15 in Russia, Tore Supra in France, and the Frascati-U in Italy. The Joint European Torus (JET), located in England, is the largest operating tokamak and produced almost 2 million watts of power in 1991 using a 90/10 DT fuel mixture. TFTR (Tokamak Fusion Test Reactor) in Princeton, New Jersey, DIII–D, at General Atomics in San Diego (Fig. 12), and Alcator C-Mod in Cambridge, Massachusetts are the currently operating fusion research laboratories in the United States.

In November 1994 the TFTR used a 50/50 mixture of DT fuel to produce more than ten million watts of power. More recently, the DIII–D device has shown that a much smaller device may be capable of achieving similar results. Many other promising fusion concepts are being studied in universities and research laboratories around the world.

Fusion's Future: Is it in the Stars?

Progress towards the development of a working fusion device has been steady and impressive, but there is still a long way to go (Fig. 14). Scientists have successfully created the 100 million degree plasmas required for fusion, and are on the verge of exceeding plasma **break-even** — the condition at which more power is produced by fusion than goes into heating the plasma.

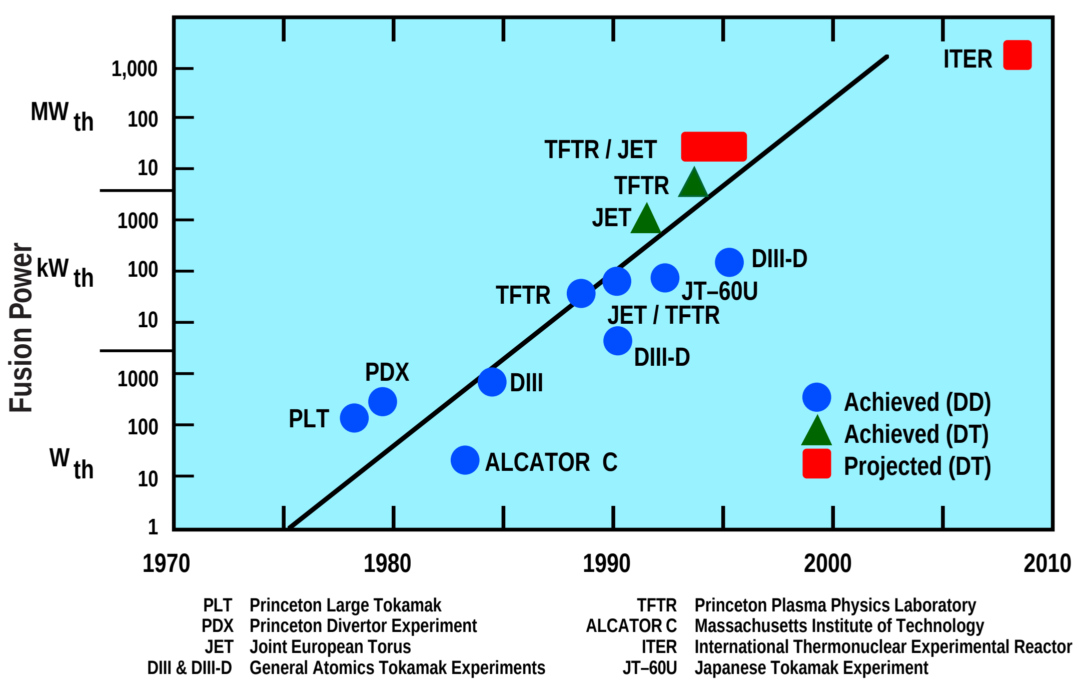
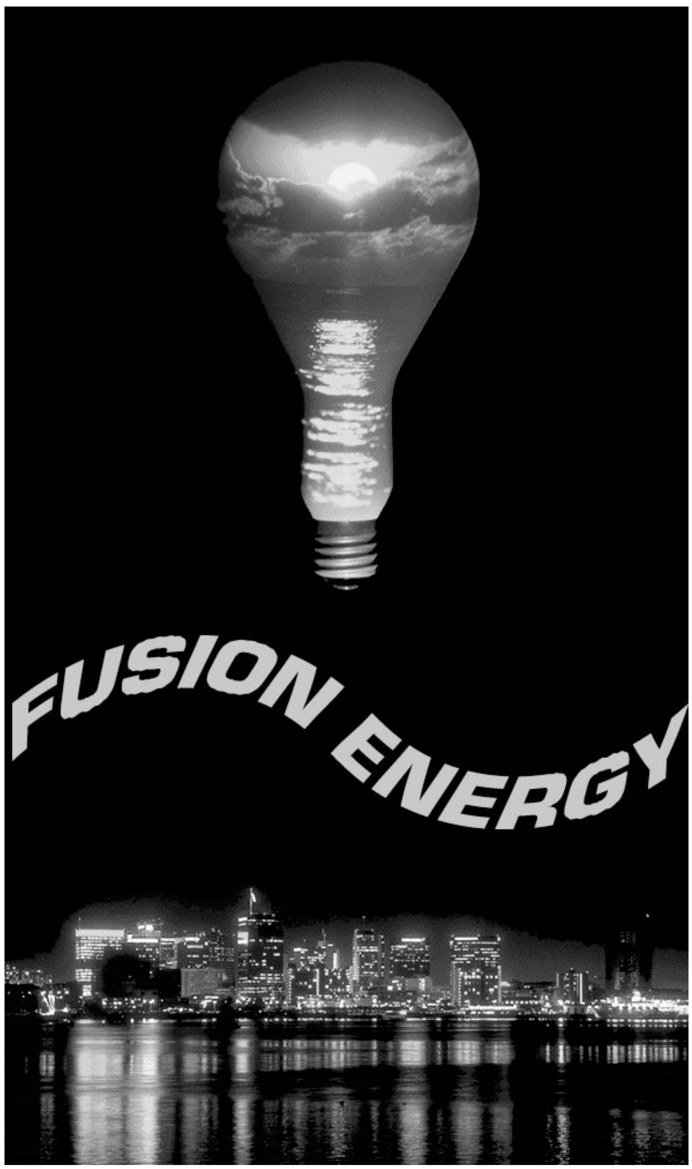


Fig. 14 - Fusion power output of major research facilities

At the present rate of success, the world fusion program should reach break even before the end of the century and through international collaboration, produce a burning plasma early in the next century. Power plants based on these ongoing experiments are expected just when we begin seeing the depletion of our most useful fossil fuels: oil and natural gas. We must plan ahead to substitute new energy sources as our existing natural resources become depleted.

The biggest problem facing the development of fusion power in the years to come is the complexity and size of the fusion devices required to make fusion a commercial reality. The ability to extract energy from a plasma hotter than the sun using super cold magnets (4 Kelvin) located meters from this fusion inferno is the next challenge confronting researchers.

In the recent years national fusion experiments have been collaborating and the fusion challenge is fast becoming an international program. The fusion program represents an important investment in our future and that of our children. Fusion provides the promise of clean, safe, abundant electrical power for the future of all mankind.



FUSION

Energy Workbook

Fusion Energy Questions

Answer the following questions by circling the appropriate answer.

1. Fusion is the process of:
   a) combining atoms of light elements into heavier ones
   b) splitting atoms of heavy elements into lighter ones
   c) sharing electrons between atoms

2. Fission is the process of:
   a) combining atoms of light elements into heavier ones
   b) splitting atoms of heavy elements into lighter ones
   c) sharing electrons between atoms

3. The primary waste product of the fusion process used for power generation is:
   a) high level radioactive waste which must be stored for millions of years
   b) harmless helium gas that can be used in blimps and party balloons
   c) Carbon dioxide gas that contributes to the greenhouse effect

4. The primary source of fuel for a fusion power plant will be:
   a) carbon stored in the trees of the remaining forests around the world
   b) deuterium found in sea water all over the world
   c) hydrocarbons found in the fossil remains of long ago
   d) uranium mined from ore deposits around the world

5. The basic energy process for which all life on earth is depends is:
   a) combustion
   b) fission
   c) fusion
   e) confusion

6. Isotopes are variations of an element with a different number of:
   a) electrons
   b) protons
   c) neutrons
   d) atoms

7. Which of the following make up the nucleus of an atom:
   a) electrons and protons
   b) protons and neutrons
   c) neutrons and electrons

8. What temperatures are needed in magnetic fusion devices on earth:
   a) 15 thousand Degrees Kelvin
   b) 100 thousand Degrees Kelvin
   c) 15 million Degrees Kelvin
   d) 100 million Degrees Kelvin

9. The nucleus is held together by the:
   a) nuclear strong force
   b) electric force
   c) nuclear weak force
   d) gravitational force

10. The nuclear strong force:
    a) acts over short and long distances
    b) acts only over short distances
    c) acts only between neutrons
    d) acts only between protons

11. Fusion requires the nuclei of two atoms to:
    a) be isotopes of the same element
    b) be brought close together
    c) overcome the nuclear force
    d) be on good terms with one another

12. Einstein's famous equation that energy and mass are equivalent can be written as:
    a) $E=qV$
    b) $E=mc^2$
    c) $E=1/2mv^2$
    d) $E=mgh$

13. Deuterium and tritium can be fused together to form:
    a) helium and a proton
    b) two hydrogen atoms
    c) helium and a neutron
    d) two helium atoms

14. The sun and other stars are contained by:
    a) gravitational confinement
    b) magnetic confinement
    c) inertial confinement
    d) All of the above

15. On the average, how much electrical power is used continuously by each person in the U.S:
    a) 1 Watt
    b) 60 Watts
    c) 220 Watts
    d) 1400 Watts

16. The primary source of fusion fuels on earth is contained in:
    a) water
    b) coal
    c) hydrogen
    d) natural gas

Comprehension & Analysis Questions

17. Explain the fusion process. What element is the best candidate for the fusion process? Explain what element and particles are produced by the reaction.

18. Identify the following energy sources with the underlying processes on the right:

1) Sun	(A) Magnetic Fusion
2) Tokamak	(B) Inertial Fusion
3) Photosynthesis	(C) Gravitational Fusion
4) Atomic Bomb	(D) Fission
5) Laser Fusion	(E) Chemical reaction
6) Radioactive Decay	
7) Combustion	

19. What type of fuels are we presently most dependent upon for electrical energy production?

20. When a pair of hydrogen isotopes are fused, does the product nucleus have more or less mass? Explain what happens to the mass.

21. Compare and contrast fission and fusion. List two major advantages to power production by fusion rather than by fission.

22. The element hydrogen has three isotopes. Common hydrogen has a single proton in its nucleus. Can you name the other two, in the order of their weight? How many protons does each have? How many neutrons does each have? Can you guess why each has the name it does?

23. An atom is composed of three smaller sub-atomic particle. Name each particle. What type of charge does each have? Which particle(s) are not contained in the nucleus? Which particle is the lightest?

24. The world is expected to run out of oil sometime in the next century. Describe some of the energy sources which will be used to compensate for loss of this resource. Explain the advantages and disadvantages of each energy source.

FUSION

Energy Workbook

Plasma Questions

Answer the following questions by circling the appropriate answer.

1. Most of the universe is made up of:
   a) plasma
   b) solid
   c) minerals
   d) liquids

2. The approximate temperature of the center of the sun is:
   a) 15 thousand degrees Kelvin
   b) 100 thousand degrees Kelvin
   c) 15 million degrees Kelvin
   d) 100 million degrees Kelvin

3. Examples of naturally found plasmas are:
   a) Van Allen radiation belts
   b) sun & stars
   c) Aurora Borealis
   d) lightning
   e) all of the above

4. Two positive charges will:
   a) attract each other
   b) excite each other
   c) repel each other
   d) do nothing

5. A proton and an electron:
   a) have like charges
   b) have opposite charge
   c) have the same mass
   d) are both neutral

6. Electrons are bound to the nucleus by:
   a) a nuclear strong force
   b) a nuclear weak force
   c) an electric force
   d) a gravitational force

7. Atomic nuclei are normally kept apart by:
   a) fast moving electrons
   b) the electrical force of repulsion between protons
   c) the nuclear force between protons and neutrons
   d) the rules of quantum mechanics

8. Plasma is commonly referred to as:
   a) the first state of matter
   b) the fourth state of matter
   c) very cold matter
   d) the rarest state of matter

9. The primary difference between the solid, liquid, gaseous & plasma states is:
   a) pressure
   b) volume
   c) temperature
   d) density

10. The temperature of a plasma is a measure of:
    a) the mass of the ions and electrons in the plasma
    b) the color of the plasma
    c) the density of the plasma
    d) the energy content of the plasma

11. The item below which is not a gaseous plasma is:

    a) the fireball of our sun and other stars

    b) blood plasma used in hospitals

    c) the ionized gas in fluorescent lights and neon signs

    d) lightning bolts and electric welding arcs

12. High temperature plasmas must be kept away from container walls because:

    a) it will produce an electric shock

    b) it will damage the wall and cool the plasma

    c) a bolt of lightening will be shot from the container

    d) a large magnetic field will be produced

13. A strong magnetic field will cause the charged particles of a plasma to:

    a) absorb magnetic field energy

    b) accelerate, increasing the temperature of the plasma

    c) circle around the magnetic field “lines of force”

    d) decrease in charge magnitude

14. A tokamak plasma is contained using:

    a) strong gravitational fields

    b) strong magnetic fields

    c) well insulated glass bottles

    d) strong electric fields

15. Plasma in a flourescent tube does not destroy the glass wall because:

    a) magnetic fields keep it from contacting the wall

    b) the product of density and temperature, or pressure, is too low to cause damage

    c) the plasma cools to a normal gas before it touches the wall

    d) the plasma is too cold to damage the wall

Comprehension & Analysis Questions

16. Explain what happens to ice as it is heated to high temperatures. What are the states of matter it changes too? What is disassociation? What is ionization? What happens to water when it is heated well beyond the temperature of the sun?

17. Give two examples of plasmas found in nature. What phenomena creates each plasma? How is the plasma confined?

18. Explain the term “plasma confinement”. How is it achieved in the sun and in fusion devices on earth?

19. Plasmas are a mixture of charged particles. Explain what happens to a plasma in a magnetic field.

20. Explain what happens to the electrons of an atom in a partially ionized state and a fully ionized state.

21. Man lives in the 1% of the universe made up solid, liquids and gases. Use your imagination to explore what life would be like if we lived in the other 99% of the universe.

FUSION

Energy Workbook

Electromagnetic Spectrum Questions

1. Another name for infrared is:
   a) visible
   b) UV
   c) heat
   d) wavelength

2. An angstrom (Å) is a unit of wavelength equal to
   a) 1 micron = 10^{-6} m
   b) 1 m
   c) the distance between the sun and earth
   d) 10^{-10} m

3. 1 mm is a wavelength found in which portion of the electromagnetic spectrum?
   a) infrared
   b) microwave
   c) visible
   d) ultraviolet

4. The electromagnetic spectrum represents:
   a) a classification scheme for radiation wavelengths and frequencies
   b) a narrow portion of visible light
   c) energy transfer between chemical bonds
   d) an electrician's guide to high voltage

5. A wavelength of visible red light is
   a) 1 mm
   b) 10-6 m
   c) 7000 angstroms (Å)
   d) 600 angstroms (Å)

6. Ultraviolet light is energy that:
   a) can be felt as heat
   b) can be harmful to DNA
   c) is emitted by an X-ray source
   d) has a wavelength of 1 Å

7. The most penetrating radiation to human tissue is:
   a) x-ray
   b) ultraviolet
   d) infrared
   e) visible

8. The colors which are visible to our eyes:
   a) are a small part of the electromagnetic spectrum
   b) are between infrared and ultraviolet in the electromagnetic spectrum
   c) have wavelengths between 4000 Å and 7000 Å
   d) all of the above

9. In a vacuum, electromagneti waves travel:
   a) at the speed of sound
   b) slower than in water
   c) at the speed of light
   d) in the direction of the magnetic field

10. Gamma-rays
    a) were made up by science fiction writers and really don't exist
    b) have very short wavelengths and high energy
    c) have very long wavelengths and low energy
    d) have longer wavelengths than X- rays

11. The reflection of the electromagnetic waves by a surface
    a) depends on the frequency, surface finish and material
    b) only works for visible light
    c) increases as the material temperature increases
    d) only works on glass surfaces

12. The index of refraction
    a) is the ratio of the speed of light in a vacuum to the speed in the medium
    b) is always greater than 1
    c) influences the direction of a wave when traveling between media
    d) all of the above

13. Electromagnetic waves
    a) are the same as pressure waves
    b) travel on spherical surfaces away from the source
    c) cannot bend around objects
    d) all of the above

Comprehension & Analysis Questions

14. Explain the difference between thermal radiation and spectral radiation

15. Microwaves are used in our society for many things. Explain some of the uses for this range of the electromagnetic spectrum.

16. Describe some of the ways electromagnetic waves are used in communication.

17. Explain why an unpolished copper plate might serve well as a good reflector of incident infrared radiation.

18. Name four or more generic types of detectors which are used to detect the electromagnetic spectrum.

19. Make believe you are a photon of energy emitted from some type of electromagnetic source (flashlight, x-ray machine, radar ...). Describe your journey as you pass through materials and reflect from surfaces.

Radiation

1. A device which measures radiation from radioactive material is:
   a) thermometer
   b) Geiger counter
   c) photo multiplier tube
   d) Gauss meter

2. Natural radioactive decay involves:
   a) splitting of the nucleus of a large atom
   b) absorption of an electron by an atom
   c) release of an electron by an atom
   d) combining of two lighter atoms to form a heavier one

3. In a nuclear reaction:
   a) energy within the nucleus is released
   b) energy can be in the form of electromagnetic and kinetic energy
   c) mass is converted to energy
   d) all of the above

4. An alpha particle is:
   a) nucleus of the hydrogen atom
   b) two neutrons
   c) nucleus of the helium atom
   d) nucleus of the uranium atom

5. Which of the following consumer items can contribute to radiation exposure?
   a) cigarettes
   b) camping lantern mantles
   c) fertilizer
   d) natural gas cooking
   e) dental ware (crowns, dentures)
   f) All of the above

6. Methods to reduce worker exposure to radioactive materials are:
   a) minimizing the time spent near the radioactive material
   b) maximizing the distance between the radioactive material and the worker
   c) using shielding between the radioactive material and the worker
   d) All of the above
   e) None of the above

7. Radon has a half-life of approximately 4 days. How long does it take a sample containing radon to decay to 1 / 8th of its original radioactivity?
   a) less than four days
   b) exactly four days
   c) more than four days
   d) It can never reach this level

8. The risk for a person in the general population is highest from:
   a) smoking 20 cigarettes per day
   b) exposure to radiation from a nuclear power plant
   c) exposure to diagnostic X-rays
   d) exposure to natural background radiation caused by radon

9. The answer to the question, "Is radiation safe ?" is:
   a) true
   b) false
   c) a poorly phrased question that can not be answered
   d) depends on the frequency of the radiation

10. The half life of an element is:
   a) time is takes to reach half the initial radioactivity
   b) time at which half the mass of the element is turned into energy
   c) time at which radioactive material is safe
   d) time after which no radioactivity can be measured

11. The major source of radiation for the general public comes from
   a) nuclear power plants
   b) natural sources on earth
   c) cosmic sources
   d) man made sources like x-rays

12. Radioactive atoms:
   a) give off surplus energy by emitting radiation
   b) are unstable
   c) change or decay until they become stable
   d) all of the above

Discussion Questions

13. Explain the difference between ionizing and non-ionizing radiation.

14. Explain what risk assessment means as related to radiation. Give examples of risks associated with radiation from TV, chest X-ray and other sources and compare it with other risks we take daily.

15. Give examples of natural radiation sources.

16. You are very concerned about radiation and you choose to receive the lowest levels possible. Explain what you would do in your daily life to reduce your radiation level. Is it possible to reduce the level to zero?

17. Identify each type of radiation as ionizing (mark with I) or non-ionizing (mark with NI).

    a) sound
    b) light
    c) alpha
    d) neutron
    e) gamma
    f) low frequency power line
    g) infrared
    h) radio waves
    i) microwaves
    j) X-ray
    k) beta

18. Sources of radiation that contribute to the dose received each year by the average American are : (enter True or False next to each)

    a) medical X-rays
    b) cosmic rays from the sky above
    c) the earth below us
    d) food we eat
    e) our own bones
    f) modern luminous watch dials

FUSION

Energy Workbook

Data Acquisition & Control

1. How many states can a single **bit** represent
   a) 1
   b) 2
   c) 4
   d) 8
   e) 16

2. How often does a 100 megahertz computer processor make a calculation:
   a) 1 second
   b) 100 seconds
   c) 10^{-6} seconds = 1 micro-second
   d) 10^{-8} seconds = 10 nano-seconds
   e) 10^{-9} seconds = 1 nano-second

3. The term **binary** refers to a system based on
   a) 0's and 1's
   b) 8 bits
   c) decimal
   d) byte
   e) hexadecimal

4. A medium for storing information is:
   a) magnetic disk
   b) paper tape
   c) optical disk
   d) photograph
   e) all of the above

5. Electrical impulses in copper wire travel:
   a) faster than the speed of light
   b) at the speed of light
   c) slower than the speed of light
   d) at the speed of sound

6. Optical methods are being used more and more for information transfer because:
   a) optical methods are faster than electrical methods
   b) optical techniques have higher data density than electrical
   c) optical techniques are insensitive to external electromagnetic radiation
   d) all of the above

7. You must send data to the Surveyor on the moon; 384 million meters from the earth. How long does it take if data travels at the speed of light (300 million meters / second):
   a) 1.28 minutes
   b) 0.78 seconds
   c) 1.28 seconds
   d) 0.78 minutes

8. The component which is at the heart of the computer is:
   a) central processing unit (CPU)
   b) magnetic disk
   c) internet
   d) vacuum tube

9. The Internet is a:
   a) game for computer programmers
   b) government controlled network for research scientists
   c) central computer with public access
   d) world wide network of computers all conversing using the same protocols

Comprehension & Analysis Questions

10. Give an example of a data acquisition tool you use. What is the capture device? What is the storage device?

11. Explain what the term "format" means in data acquisition. Explain why standard formats are important.

12. List some of the advantages of the computer.

13. At your school you have just been given the job of recording student attendance. Create a system that will perform this function. Describe the components and how they work together to record student attendance. What detector would you use? How could you make sure it's tamper proof? Would this system save teacher and class room time?

FUSION

Energy Workbook

Engineering Analysis, Design and Manufacturing Questions

1. The term **CAD** refers to:
   a) Computer And Data
   b) Computer Aided Design
   c) Construction And Design
   d) Cost, Audit & Design

2. An engineer must consider which of the following parameters in a typical design:
   a) stresses
   b) thermal
   c) manufacturability
   d) cost
   e) all of the above

3. A temperature of 100 degrees Celsius is equivalent to:
   a) 273 degrees Kelvin
   b) boiling temperature of water at normal atmospheric pressure
   c) freezing temperature of water
   d) room temperature

4. The international standard of measurements is based on:
   a) metric system
   b) British system
   c) combination of British & metric system
   d) no international standard exists

5. Carbon is used as a thermal protector in fusion devices because it:
   a) retains its strength at high temperatures
   b) is an inexpensive material
   c) moderates neutrons from the fusion process
   d) conducts heat better than pure copper

6. Inertial cooling refers to:
   a) the exchange of plasma momentum at a surface wall causing cooling
   b) conduction of heat to a cooling system
   c) adsorption of heat by a material with an increase in temperature.
   d) all of the above

7. A milling machines is:
   a) equipment used to diagnose the plasma temperature
   b) equipment used in the manufacture of flour
   c) a detector for the determination of neutron energy
   d) equipment used to machine surfaces on metal components

8. Computers are used in engineering to:
   a) develop part drawings
   b) perform structural and thermal modeling
   c) control milling and other metal working machinery
   d) all of the above

9. When a high energy plasma comes in contact with a cold surface
   a) the plasma cools down
   b) the surface absorbs energy and heats up
   c) the surface is eroded
   d) all of the above

Comprehension & Analysis Questions

10. Explain the process required to design, test and manufacture a thermal tile used for protection inside a tokamak fusion device. What material properties are required and what are some materials which could be used?

11. Explain what happens to metals as the temperature is increased. How is material strength effected?

12. Fatigue is the process of material weakening from cyclic application of load. Give some examples of equipment you use which might fail from fatigue loads.

13. Most present day fusion test experiments are transient in that the plasmas last very short times (1–60 seconds). Inertial cooling of components is possible with heat removed between tests. Future devices cannot rely on this technique. If you are the design engineer for development of a continuous cooling system explain what would be required. Give examples of types of fluids which might be used. What are the important parameters?

A Fusion Glossary

Alpha or α Particle - A positively-charged particle consisting of two protons and two neutrons, identical with the nucleus of a helium atom.

Beta or β - The ratio of plasma pressure to magnetic field pressure.

Blanket - The physical system surrounding the hot plasma that absorbs fast neutrons, converts the energy into heat, and breeds tritium.

Breakeven - The condition where fusion power produced in the plasma equals the heating power put into the plasma.

Current Drive - Any of a number of mechanisms to produce or drive current in a toroidal plasma by application of external devices such as neutral beams or rf power generators.

DIII-D - The shaped, diverted tokamak operating at General Atomics. The approximate characteristics are: major radius 1.7m, minor radius .7m, toroidal field 2.1 Tesla, plasma current 2 MA.

DT - Mixture of fusion fuels: D = Deuterium, T = Tritium. A 50/50 mixture of these hydrogen isotopes is the most reactive of all fusion fuels. Relative to hydrogen, Deuterium contains 1 extra neutron and Tritium contains 2. Small amounts of deuterium are found in water; tritium can be a byproduct of the fusion process.

Electron - A stable elementary particle which is the negatively charged constituent of ordinary matter.

Ignition - The condition in which the fusion reactions in a plasma maintain the plasma temperature thereby eliminating the need for heating power from external sources.

Ion - An atom or molecule which has gained or lost one or more electrons, and which has thus a negative or positive electric charge.

Isotope - One of a group of nuclides that have the same number of protons in their nuclei, that is the same atomic number. However their atomic mass differs because they have different numbers of neutrons.

ITER - International Thermonuclear Experimental Reactor. The major world-wide design activity defining a possible fusion engineering test reactor based on the tokamak concept. Approximate characteristics are currently defined to be: major radius of 8.1 m, minor radius of 2.8 m, toroidal field of 5.7 Tesla, plasma current of 21 MA.

Kelvin - The basic unit of thremodynamic temperature. The Kelvin scale starts with zero at absolute zero, the point at which molecular motion (i.e. heat) ceases completely. Water freezes at 273.15K. (Note: the term *degrees Kelvin* was dropped in 1967, thus the symbol is K and not °K.)

keV - One thousand electron volts. An electron volt is a unit of energy which is equal to the energy acquired by an electron when it passes through a potential difference of 1 volt in vacuum. The temperature associated with 1 keV is 11.605 million kelvin.

Lithium - Atomic number 3. Group 1A (alkali metals). A silver-white metal, harder than sodium but softer than lead. The lightest of the elements that is solid under standard conditions. It is tough and may be drawn into wire or rolled into sheets.

Major Radius - The radius of the large circle of a torus.

MeV - One million electron volts.

Minor Radius - The radius of the small circle of a torus.

Neutron - An elementary particle which has approxmately the same mass as the proton, but lacks electric charge, and is a constituent of all nuclei having a mass number greater than 1.

Nucleus - The central, positively charged dense portion of the atom.

Plasma - The fourth state of matter, consisting of a collection of charged particles, such as in the sun. Has some properties of a gas, but differing from a gas in being a good conductor of electricity.

Proton - Positively charged constituent of ordinary matter found in the nucleus of an an atom and having approximately the same mass as a neutron.

RF - Radio frequency.

T - Tesla, a unit of magnetic field strength

Tokamak - The leading toroidal confinement concept named after a Russian word for high current. The magnetic fields are provided primarily by cylindrical magnets (toroidal field) and internal plasma current (poloidal field).

Toroidal - Having a specific geometrical shape like a doughnut. The toroidal direction is along the large circular axis of the torus.

Uranium - Atomic number 92. A white metal, ductile and malleable. Uranium is found in nature in three isotopes of mass numbers 238, 235, and 234, with relative abundances of 99.28, 0.71, and 0.006%, respectively. U_{235} is important because it undergoes the nuclear fission reaction with slow neutrons.

X-rays - Electromagnetic radiation of extremely short wavelength, extending from the extreme ultraviolet into the gamma ray region, that is from 10^{-7} to 10^{-9} centimeter.