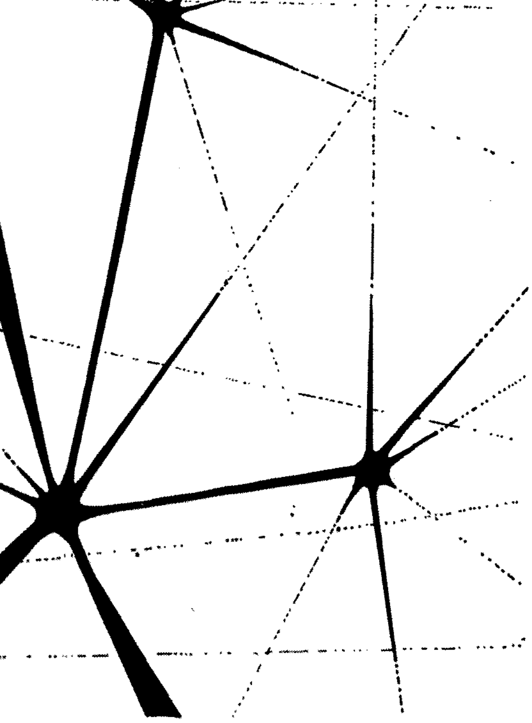


USING FISSION

by Joel Miller

INTRODUCTION

Atoms are just like people, both are lazy. Energy is a measure of work, i.e., more work implies more energy. Atoms do not like to work, hence they try to reduce the energy in their atomic system. For different elements the energy reduction occurs by reaction, e.g., an energetic sodium atom reacts with an energetic chlorine atom to form a less energetic salt molecule. Most of the energy lost in the system is transformed into heat. When more work in the form of heat is given up the resulting atom is more stable, or lazier.

Atoms of a single element exist in many nuclear states. Since some of these states are more stable than others, internal transitions occur to form a less energetic atom. Natural atoms can emit energy by three methods; alpha particles, beta particles, and gamma rays. Atoms which emit part of their mass are alpha sources, while beta emitters yield plus and minus charged electrons. Gamma sources yield energy in the form of electromagnetic waves.

FISSION PROCESS

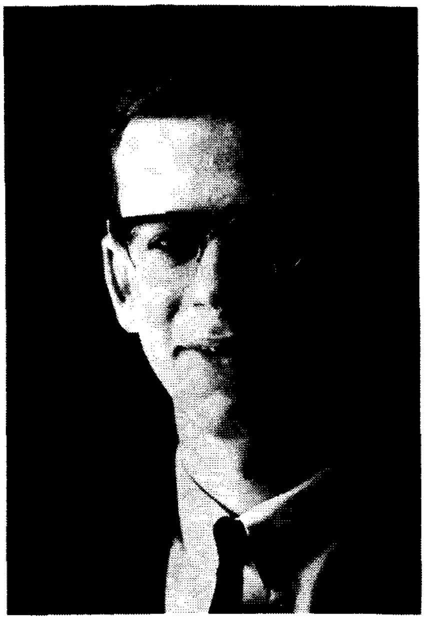
When Uranium-235 absorbs a neutron, an atom of Uranium-236 is formed. Uranium-236 is very unstable, and may give off an alpha particle to become an atom of Thorium-232. More probably the U-236 will explode. It breaks into two or more smaller fragments, and several neutrons. Heat is also evolved, hence the newly-formed atoms are more stable than the original U-236 atom. Each of the fragments formed might not be in their most stable nuclear configuration, and may decay further. This process is known as nuclear fission.

The principles of fission can be simply demonstrated using ping pong balls and mouse traps. Several hundred mouse traps are placed in a cocked position (this represents an energetic mouse trap state, and like energetic atoms, a transition to a less energetic state is likely). Two ping pong balls are delicately placed on each mouse trap, so that when the mouse trap is set off the balls are launched. Each mouse trap may be visualized as a Uranium-235 atom, while each ping pong ball represents a neutron.

Fission is initiated by a U-235 atom absorbing a neutron and exploding. By analogy, gently tossing an extra ping pong ball on the table striking a cocked mouse trap, two balls are fired instantaneously. These two new ping pong balls are capable of hitting two more mouse traps, emitting many more ping pong balls. In a very short time interval the table is popping with ping pong balls. Each time a mouse trap gets rid of its pair of ping pong balls energy is released. The potential energy in the spring of the mouse trap is transformed into ping pong ball kinetic energy. This, in effect, reduces the energy of the mouse trap system. This is basicly how atomic fission occurs in a nuclear reactor.

If the launching mechanism on the mouse trap is shoddy, the two neutrons may be emitted prematurely. Then these two neutrons are capable of starting a sustained nuclear fission reaction. This phenomena of spontaneous fission occurs in Uranium-235. If a fission reaction is to be sustaining,

ABOUT THE AUTHOR



Joel Miller wrote this article after taking a course in Nuclear Engineering Technology. This course also inspired him to take another in Radiochemistry. Joel is the Advertising Manager for the Wayne Engineer, and also takes time out from his studies to girl-watch occasionally.

each such reaction must release a neutron which will cause fission in another atom. In terms of our analogy, when a stray ping pong ball strikes a mouse trap and releases two more ping pong balls, one of these two balls must hit another mousetrap which has not been triggered. If one neutron flies off in the wrong direction, the second one must (for sustained reaction) hit another nucleus. In an actual nuclear fission more than two neutrons may be released per fission, the average number being 2.51.

USING THE REACTION

A certain percentage of Uranium-235 atoms fission spontaneously, inciting a potential nuclear chain reaction. A certain percentage of naturally occurring uranium is Uranium-235. Therefore, a critical mass can be determined. The critical mass is the minimum amount of a fissionable substance which will sustain a fission reaction.

In an actual nuclear reaction, there exist many billions of atoms. Thus one fissioned atom need not yield one neutron, but, on the average, there is one released neutron per fissioned atom. If conditions permit more than one fission causing neutron to be released per fissioning neutron, the reaction quickly escalates into a political hazard called an atomic bomb. In an atomic bomb, conditions are such that mass, greater than the critical mass, is instantaneously formed. Due to the quickness of the numerous resulting fissions, an enormous amount of energy is given off. An atomic bomb is politically labeled "dirty" because, along with the heat involved, many extremely radioactive fission fragments are thrown into the atmosphere, yielding a lingering and deadly fallout.

The interaction between a neutron and a molecule is measured in terms of a microscopic cross sectional area. A neutron may strike an atom and cause fission, or it may be absorbed or scattered away from the atom. The total neutron cross-sectional area is the sum of the fission, absorption, and scattering cross-sectional area. This is expressed in units of barns. The cross-sectional area is the area presented by the atom for a particular neutron interaction. The relative sizes of the cross-sectional areas for absorption, scattering, and fission are proportional to the probability of neutron absorption, scattering, and fission. For example, Boron-10 has a neutron cross-section for absorption which is much greater than its scattering cross-section. Hence, neutron absorption is the prevailing phenomena associated with Boron-10. In Uranium-235 the fission cross-section is much greater than the absorption or scattering cross-section. Therefore, when U-235 atoms are bombarded with neutrons a much higher probability of fission occurs. It is interesting to note that the absorption cross-section for U-235 is not zero. This implies that U-235 atom will lower its internal energy by absorbing a neutron and decay by emitting an alpha particle as well as the more probable mode of fissioning into several new elements and releasing neutrons and energy.

Uranium-238 has a small fission cross-section with respect to its absorption, fission, and scattering cross-section, and Uranium-235's fission cross-sectional area. This indicates that when a sample of a U-235 and U-238 mixture is bombarded with neutrons, U-235 will most probably fission while U-238 will absorb a neutron and decay by emitting an alpha particle and forming a particle which absorbs an electron to create a Plutonium-239 atom. Plutonium-239, like Uranium-235 is readily fissionable.

It should be noted that the ability for a neutron to interact with an atom is not only proportional to the cross-sectional area, but also is a function of the velocity of the neutrons. For the Uranium nuclides mentioned above, the relative sizes of the cross-sectional area are for neutrons that are in thermal equilibrium with the surroundings. In the case of U-235, fast neutrons are less likely to interact than thermal neutrons. For U-238 and Pu-239 the faster neutrons are more likely to cause fission than absorption.

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In a nuclear reaction U-235, U-238, and Pu-239 are present along with the necessary neutrons which initiate fission. U-235 will fission with slow neutrons, while U-238 and Pu-239 will fission with fast neutrons. The relative rates at which each of these substances fission is a function of two quantities; the amount of each substance present, and the velocities of the neutrons causing fission. The initial neutron from the source is a slow one and allows a U-235 atom to fission. This creates two neutrons which are of the fast type; one of these must strike another atom yielding more neutrons.

As an illustration of this, consider the mousetrap analogy again. Since the mousetrap is constructed on a piece of wood, the ping pong ball may hit part of it without setting it off. The small area of the mousetrap that the ping pong ball must hit to cause fission is the microscopic cross-section of the trap. If a ping pong ball does not hit the part of the mousetrap which is sensitive for ping pong ball launching, the ball will bounce off the table or toward another mousetrap. While bouncing, the fast ping pong ball loses velocity and soon becomes a slow ping pong ball.

In actuality, fast neutrons are slowed down by collisions with atoms. To further slow down fast neutrons, a substance called a moderator is used. A moderator has a large neutron cross-section for scattering which allows fast neutrons to be slowed down by collision as water slows down a speeding bullet. A moderator also has negligible cross-sectional areas for absorption and fission. This permits fast neutrons to be slowed down but not removed from the reaction chain. Graphite or pure water may be used for this purpose in a nuclear reactor.

THE NUCLEAR REACTOR

A nuclear reactor consists of several components. A nuclear fuel element is necessary for the operation of the reactor, as is a coolant. A coolant is needed to keep the reactor core from getting too hot and melting. Also essential for the reactor's operation is a moderator for keeping the reactor supplied with slow neutrons. A thick shield is necessary to prevent stray neutrons from hitting people. Control rods are needed so the power level of the reactor can be adjusted. A purpose for existence is also necessary for each reactor. This may be to furnish electric power, to propel a submarine, to manufacture new nuclides, or to conduct pure research.

The coolant for a reactor may be water or it may be compressed gases, such as hydrogen or carbon dioxide. Since metals have good heat transfer properties, liquid metals are sometimes used as coolants. An example of this is in the Fermi Nuclear Reactor located in Monroe, Michigan which is cooled with liquid sodium.

Control rods, generally made of cadmium, are used to limit the neutron population inside the reactor core. Cadmium has a high neutron cross-section for absorption. Placing the control rods completely inside the core causes a certain fraction of the neutrons to be absorbed. By withdrawing the control rods, less cadmium is exposed to the neutrons, therefore less will be absorbed and more will be capable of sustaining the nuclear fission process.

Moderators are generally either graphite or water. The water used must be extremely pure. Impurities, such as chloride ions, will become radioactive while pure water will not. Heavy water (deuterium oxide) is a much better moderator than common water, but it is expensive. By determining the size of moderator necessary along with the budget, and using as much water as possible (since water is a liquid which can be poured, and is cheaper than pure graphite, although the moderating properties are not as good) the type of moderator for any reactor can be determined.

Safety is also quite important in reactor construction. Radiation has a tendency to knock existing atoms out of place in a molecule. When an organic compound or water is exposed to radiation, hydrogen atoms are knocked out of molecular position. This forms a highly reactive chemical species (called a free radical) which is capable of instantaneous reaction with other free radicals forming a new compound. People were designed to be made of specific molecules, each with many atoms in a very specific order. When this molecular arrangement is changed, as is the case with exposure to radiation, people change. Since people are people and do not know how to be anything else, they get sick. If the radiation damage is not too severe the body is able to regenerate the needed atoms and recover.

To prevent radiation striking people a thick shield is used to stop the potentially dangerous radiation. A shield must be able to absorb neutrons without damage to itself. In general, a denser substance (provided a neutron or gamma interaction does not form an undesirable effect) makes a more desirable shield. Lead makes an excellent shield, as does concrete, even though more concrete is needed to do the same stopping job that lead does. Water is also a good shield.

REACTOR FUEL

The fuel for a reactor designed to operate on fast neutrons is Uranium-233, which forms fissionable Pu-239. The most common reactors now in operation use slow neutrons and are fueled by Uranium-235. Seven tenths of one per cent of naturally occurring uranium ore is Uranium-235.

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USING FISSION

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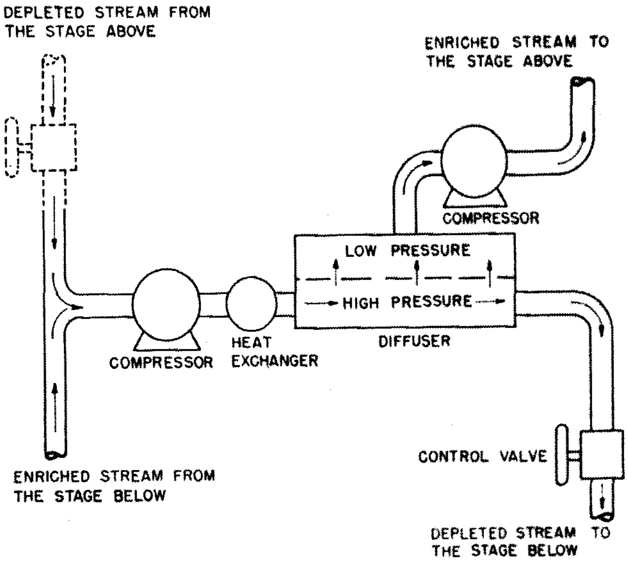
In a nuclear reactor, in order to keep the size of the reactor down and the efficiency up, the fuel must be enriched in Uranium-235. An atomic bomb is designed to operate on one hundred per cent pure Uranium-235.

The only physical or chemical property that is not identical to both Uranium-235 and Uranium-238 is mass. That is the mass of one gram-mole of pure Uranium-235 is three grams less than one gram-mole of pure Uranium-238. By reacting naturally occurring Uranium with fluorine gas, an extremely poisonous and corrosive gas, Uranium Hexafluoride, is formed.

From the kinetic gas theory, atoms in thermal equilibrium each possess the same kinetic energy. Since Uranium-235 Hexafluoride is lighter, it must travel at a greater velocity than does the Uranium-238 Hexafluoride. This also implies that the momentum of the U-235 form of the Hexafluoride is greater than the U-238 form of the Hexafluoride, while both species are in thermal equilibrium.

By pumping the gaseous mixture into the diffusion apparatus, as shown in Figure 1, the Uranium-235 Hexafluoride diffuses faster and hits the membrane faster with more momentum than the U-238 form of the gas. Thus, more of the Uranium-235 Hexafluoride atoms pass through the membrane than their Uranium-238 counterparts. The gas in the upper portion of the apparatus is richer in U-235 than that in the lower portion. To stimulate the gas to advance toward the upper portion of the apparatus a pressure gradient is applied to the system.

The entire system consists of a cascade of several thousand units, each identical to Figure 1. The gas coming out of each unit is divided so that part goes on to the next unit while the remaining gas is recycled. Samples of the gas taken at various points in the cascade show the enrichment of U-235 to vary from 0.7% at the first unit to 100% at the last unit.



SCHEMATIC DIAGRAM OF A STAGE

FIGURE 1

After a reactor operates for a while, the fission fragments which are formed in the nuclear reaction clutter up the fuel so that the remaining fuel is unusable. For example, after operating a reactor at the equivalent of ten megawatts for one hundred days, one gram of fission fragments is formed. The fission fragments are highly radioactive but non-fissionable and render the reactor subcritical. After the fuel is useless, it is removed and replaced. The fission fragments make the spent fuel hazardous to people and must be placed in a shielded area and allowed to decay without causing too much harm. As the fuel still contains useful and extremely valuable fuel it is chemically processed to obtain the useful Uranium and Plutonium for further reuse. The fission products are also quite valuable, but chemical technology has not been able to adequately separate each of these minutely appearing nuclides at reasonable cost.