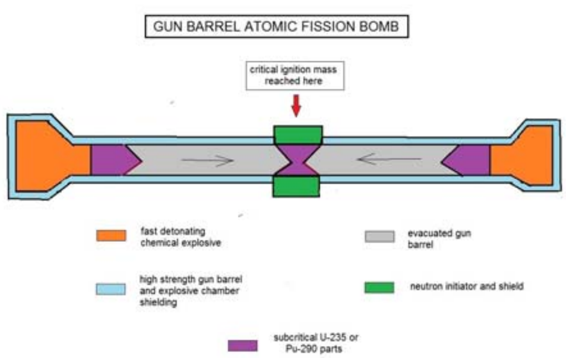
WHAT ARE THE FOUR MAIN USES OF NUCLEAR ENERGY?

Over the last eighty years nuclear energy has found a wide range of applications starting with nuclear bombs in the 1940s, to nuclear reactors in the 1950s, to medical applications in the last four decades, to the as yet unfilled promise of nuclear propulsion for space. We wish in this article to discuss the more important aspects of each four of these areas of nuclear energy.

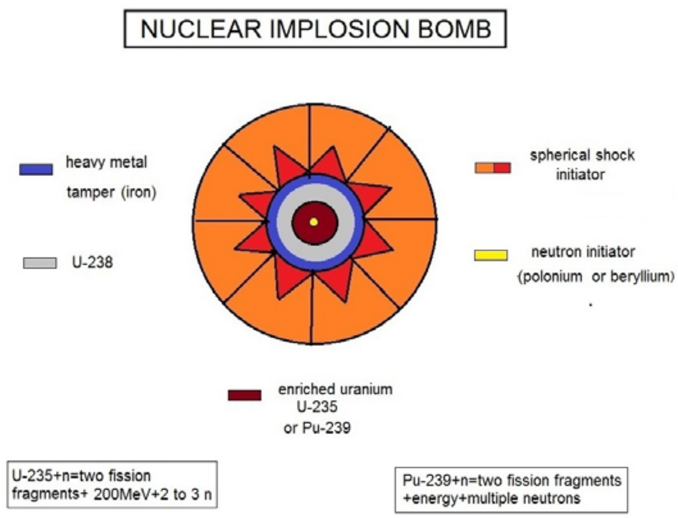
NUCLEAR BOMBS

Work in this area began in the late 1930s when it was discovered that neutron bombardment of uranium nuclei can lead to a splitting of U-235 into two high energy nuclear fragments (fission) plus the additional release of several neutrons. This can, under correct conditions, produce a chain reaction with the release of a huge amount of energy given by Einstein's Law that the energy release per fission equals $E=mc^2$, where m is the mass change in the reaction and c the speed of light. This fact led to the initiation of the WWII Manhattan Project at Los Alamos driven by the fear that Germany might be working on a similar project. By 1945 the US had produced several nuclear bombs and promptly proceeded to drop two of them on Japan. The first of these bombs was Little Boy, a 12KT of TNT equivalent nuclear bomb dropped on Hiroshima on August 6th of 1945 killing about 140,000 civilians. It was a gun barrel device in which two subcritical uranium projectiles where made to run into each other at high speed producing a critical assembly and subsequent explosion. Here is a modified sketch I have made of the device-



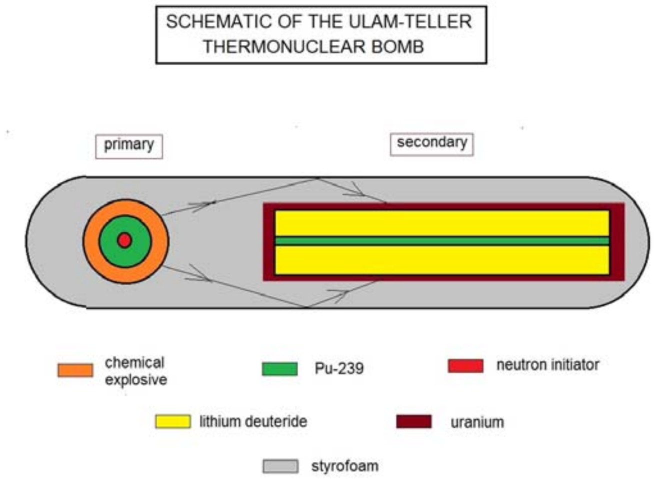
The originator of this type of bomb was Klaus Fuchs we worked at Los Alamos while secretly spying for the Russians. The nuclear fuel used was enriched uranium U-235.

The second type of nuclear bomb developed at Los Alamos was a spherical implosion device. Much credit for its functioning was due to George Kistiakowsky, an expert in shape charge chemical implosions. The first version of this device was tested in the Nevada desert (Project Trinity) in July 1945 and an identical copy of this bomb was dropped on Nakasaki several days after Hiroshima. The device was known by the code name Fat Man. It looked like the following-



It used plutonium Pu-239 as its nuclear fuel. All later fission bombs including those developed by Russia, England, Israel , France, India, Pakistan, China, North Korea, and soon Iran, are based essentially on one or the other of the two above designs.

Starting in the late 1940s people began talking about developing even much more powerful nuclear bomb using nuclear fusion. This process combines two hydrogen nuclei to produce helium. The temperatures required to produce such a fusion is millions of degrees and can only be triggered by something like a fission bomb. How to do this occupied the attention of Edward Teller and Stanislaw Ulam. It was Ulam who first suggested that one separate the fission explosion from the fusion process. His original idea being that an ellipse has two focal points and hence what happens at the first focus should transfer to the second. Teller ran with this suggestion modifying the idea of converging shock waves into a device where the x-rays created by the fission reaction focused in on a cylinder of lithium deuteride as shown in the following sketch-



Such a bomb, unlike a fission bomb, has no size limitation and can lead to such monstrosities as the Russian 50 megaton Tzar bomb. A hundred times smaller thermonuclear device of 0.5 MT can completely destroy any large city in the world including all its inhabitants.

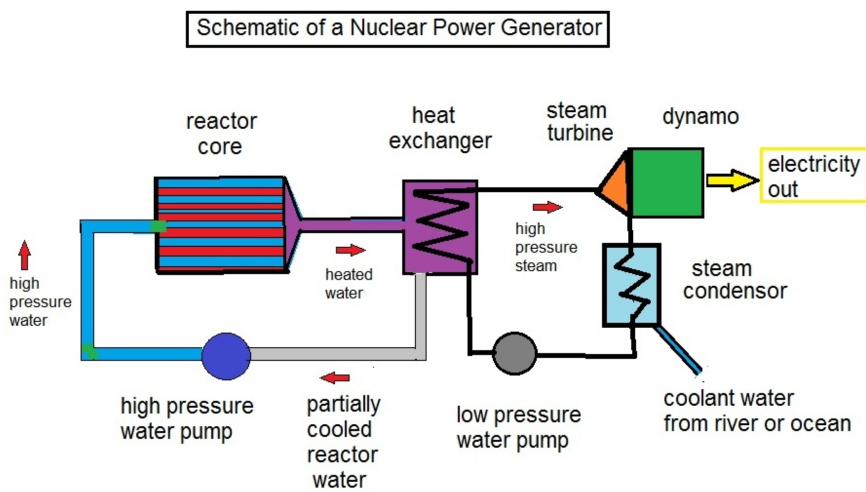
Today the construction of nuclear bombs has become a simple matter. The poor man's version requires only a nuclear reactor filed with slightly enriched uranium . This uranium is bombarded by neutrons to form chemically separable plutonium Pu-239. If one then takes two sub-critical masses of this plutonium and collides them in a gun barrel arrangement a nuclear bomb will have been created. It is believed that north Korea, the latest nuclear power, used such an approach.

As a sidelight I have met both Teller and Ulam here in Gainesville. The former during a star wars (Stratigic Defense Initiative) talk at the University of Florida. It turns out that my father and Teller where contemporaries at the University of Leipzig in the early 1930s and got their Phd degrees there about the same time. I met Stan Ulam while he was a visiting professor here at UF in the early1980s. We talked a bit about combinatorics but never discussed his Los Alamos days or his prime spiral which I was able to simplify considerably showing that all prime numbers above three have the form 6n+1 or 6n-1.

NUCLEAR REACTORS

It was realized starting in the early 1940s that nuclear reactors can be used for peaceful purposes by generating electricity. Enrico Fermi was a pioneer in this field producing the world's first controlled chain reaction using uranium in a graphite reactor. By the 1950s improved nuclear reactors where being constructed commercially throughout the world . Most of these where pressurized water reactors (PWR). By 2000 there were about 450 functioning reactors world-wide with about a quarter of these found in this country. Since that time the demand for additional reactors has dropped off considerably because of the public's legitimate concern concerning nuclear contamination produced by the well publicized reactor accidents such as at Three Mile Island, Chernobyl, Fukushima and most recently involving the reactor failure of a nuclear propulsion cruise missile at a test site along the White Sea in north-west Russia. It is not clear what the future holds for this form of electricity production. At the moment nuclear reactors generate about 11% of the electricity in the world. It is difficult to see how one can do without them due to the ever increasing demand for electric power while at the same time trying to reduce carbon based combustion which aggravates global warming and realizing that alternate sources of energy such as wind or solar power will never be able to produce more than only a small fraction of the world's electricity requirements..

Let us look at a typical functioning nuclear reactor used for producing electricity. Here is a sketch which I made-



It consists of two basic loops each driven by separate pumps. The left loop carries water under high pressure into the nuclear reactor where it is heated by the controlled fission reactions occurring in parallel fuel rods. The heated water (still in liquid form) exits the reactor and goes to a heat exchanger where the low pressure water loop on the right produces superheated steam which drives a steam turbine which in turn spins a dynamo to produce electricity. After passing through the turbine, the spent steam is condensed by an external cooling source such as river or ocean water. The right pump next pumps the cooled water back into the heat exchanger. The first loop typically finds itself in a containment building to prevent wide spread nuclear fragment dispersion in case of an accident. The accidents at Chernobyl and Fukushima show that such precautions don't always work. Another problem with this type of electricity generation is that it leads to a great deal of nuclear waste contained within the spent fuel rods. So far no one has been able to find a safe storage place guaranteed to be secure for the thousand of years it will take for the radiation from these nuclear fragments to die down sufficiently.

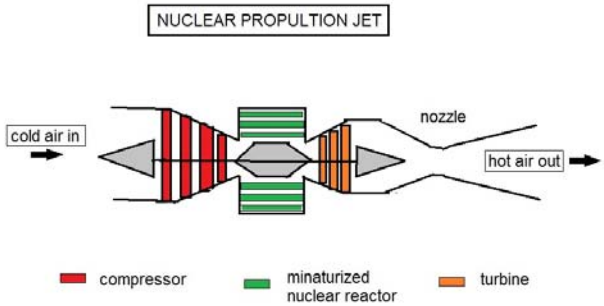
NUCLEAR MEDICINE

The field of nuclear medicine deals with (a) the injection of radioactive atoms into the human body to see where there are some troubling points in the circulation system such as near tumors or other deposits, and (b) the use of both radioactive and non-radioactive particle beams to destroy internal cancer cells without requiring surgical intervention. The fathers of nuclear medicine are E.O.Lawence , inventor of the cyclotron and 1939 Nobel Prize winner, and his brother John Lawrence, a professor at the Yale medical school. Starting in the mid 1930s the brothers used high energy electron beams created by a cyclotron to form as variety of radioisotopes which could be injected into human arteries for both medical diagnosis and the destruction of cancerous cells. As an alternative for using concentrated xrays for tumor destruction during the 1960s, cobalt 60 beta emitter beams where developed. These beams for the first time offered focusing capabilities in the sub-millimeter range. Also PET(positron emission tomography) was developed. The latest medical tools has been the creation of proton beams by means of cyclotrons to kill internal cancer cells while producing only minimum damage to the surrounding healthy cells.

NUCLEAR PROPULSION

The one area where nuclear energy has not yet been adequately harnessed is nuclear propulsion. NASA worked on project NERVA in the 1960s using a nuclear generator to heat hydrogen and then drive it out through a nozzle with a specific impulse about twice that of a chemical hydrogen-oxygen combustion system. The project never made it to the experimental stage and efforts ceased after1973. Since that time little extra effort in nuclear propulsion has been made by the US. On the other hand, the Russians have been working on a nuclear propulsion system involving a liquid core reactor where the fluid is seeded with fissile isotopes. Recently they had a major accident in their efforts killing several scientists and contaminating a considerable area around their test site along the White Sea in northern Russia. This missile is referred to in the US literature as Skyfall. The objective has been to build a cruise missile capable of prolonged flight at near ground level to avoid radar detection. Such a cruise missile, if it is ever perfected, will be able to carry a nuclear warhead to any where in the world without detection and flying at supersonic speed near its target. To avoid a sonic boom and hence detection, the cruise missile will need to fly at sub-sonic speeds until shortly before reaching its target.

I give you here an idea of what a atmospheric based nuclear jet propulsion system would look like-



The problem with such a device is that it would spew out fission fragments with the heated air passing through the reactor causing environmental problems. Several decades ago I had some interesting discussions with Hans von Ohain(1911-1998), the co-inventor of the jet engine. He spent several winters here in Gainesville giving our aero-space students first hand knowledge of how a jet engine works.

SUMMARY

We have discussed the various uses of nuclear energy including nuclear bombs, nuclear reactors, radioisotopes in medicine, and potential nuclear propulsion. The discussion shows both good bad aspects of the technology. Certainly electric power generation is a major plus while nuclear proliferation of nuclear bombs remains a major problem. Also, the environmental effects of nuclear power cannot be ignored. It would be a major catastrophe if our food chain where to become involved. Some nuclear critics already claim that most of the fish population in the pacific has been affected by the Fukushima accident. One will have to tread very carefully now and in the future to weigh the beneficial and detrimental aspects of nuclear power.

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