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Why Germany needs a new reactor for neutron beam research

by Caroline Hartmann

Whatever important knowledge has been won in recent decades concerning the composition of matter, it has been neutron radiation that has enabled scientists to make most of these discoveries. That is why the Nuclear Science Department of the Technical University of Munich, Germany has requested permission to build a new, more powerful neutron beam generator (FRM) at its Garching campus. Without this permission, many branches of basic science in Germany could not continue work.

To grasp the importance of this issue, we must review the many applications of neutron radiation in science. There are only 11 reactors worldwide that can be used for such neutron beam research as the irradiation of silicon (NTD irradiation). They are located in Sacley and Grenoble, France; Studsvik, Sweden; Risoe, Denmark; Missouri, U.S.A.; Kjeller, Norway; Lucas Heights, Australia; Seibersdorf, Austria; Villigen, Switzerland; Chalk River, Canada; and Japan.

Since public opinion in most western countries is rather opposed to basic science, a build-down of these capacities is to be expected, whereas in fact they ought to be increased. There are ten scientific institutions in southern Germany alone waiting to get access to a new source of neutron beams.

Environmentalist groups have already begun to voice opposition against the new reactor at Garching. They point out that this reactor needs highly concentrated uranium-235 (^{235}U) to work, an isotope which is also used to build atomic weapons. The new reactor is planned to replace the old research reactor which has operated at Garching since 1957, called "the atomic egg" because of the shape of the building housing the reactor.

The new FRM has a power five times greater, and will create a usable flux of neutrons 50 times greater than the old one. This high-density flux of neutrons will be created by using a moderating tank filled with heavy water that will be much larger than the one used presently, and will consist almost exclusively of what are called "slow" neutrons, which are especially well-suited for most such experiments. The Upper Bavarian administration has supported the request. The final decision on whether the reactor may be built, has to be taken by the Bavarian minister of the environment.

History of neutron research

The neutron was first identified as one of the two particles forming the core of atoms in 1932 by James Chadwick. It does not have an electric charge, and a mass of $m_0 = 1.675 \times 10^{-24}$, comparable to the mass of the positron, which is the other particle in the core of the atom. In 1935, Enrico Fermi was the first to "shoot" neutron particles at atoms in order to create artificial elements called "transuraniums." Lise Meitner, Otto Hahn, and Fritz Strassmann proved that these "transuraniums" in fact were not larger than uranium, but fractions of ^{235}U.

These experiments not only started the era of nuclear fission. Researching the properties of neutrons and their role in the transformation of elements, scientists increasingly became aware that they are a unique tool for many applications in materials research, the physics of solid bodies, biology, biophysics, and medical research. Their reciprocal effects with other materials are dependent on their own energy level, their kinetic energy. A distinction can be made between thermal neutrons, with an energy of 0.01-0.1 electron volt (eV), and fast neutrons, with an energy of more than 100 million electron volts (MeV).

How do neutrons 'work'?

High-energy neutrons are created as follows: First, beryllium is irradiated with alpha particles, which causes the beryllium to emit thermal neutrons. These in turn are used to irradiate and split uranium ^{235}U. Each uranium atom split emits two or three fast neutrons. From there, fast neutrons are directed to cross a moderator (water), slowing them down. They will then be used to continue the process, causing a chain reaction.

There are always many thermal neutrons in the vicinity of any nuclear reactor. In a research reactor, these thermal neutrons can be directed via steel conduits to various experimental apparatuses. The fast neutrons thus created will mostly be used for medical irradiation therapy. In 1968, scientists at the old reactor in Garching found a special form of slow neutrons called "ultra-cold" neutrons, which have opened the door to a entire new branch of neutron research.

One brach of science where neutron beams are indispensable today, is materials research. Such materials as metals, ceramics, fluids, high-temperature superconductors, ion conductors, semiconductors, and macromolecular materials such as synthetics and rubber, are being tested for their properties and behavior. Experiments are also ongoing to develop entirely new materials with special characteristics.

Neutrons in materials research

In the most simple application of neutrons, neutron radio graphics, the object is examined using neutron radiation in much the same way that X-rays are used. The object is placed into the path of the neutron beam, which is directed at an electronic image-processing unit or a neutron-sensitive film. This technique is applied in the aerospace industry to check soldered joints, glued joints, or to search for corrosion. It is also used to observe the process of binding and drying of concrete, which is important for construction research.

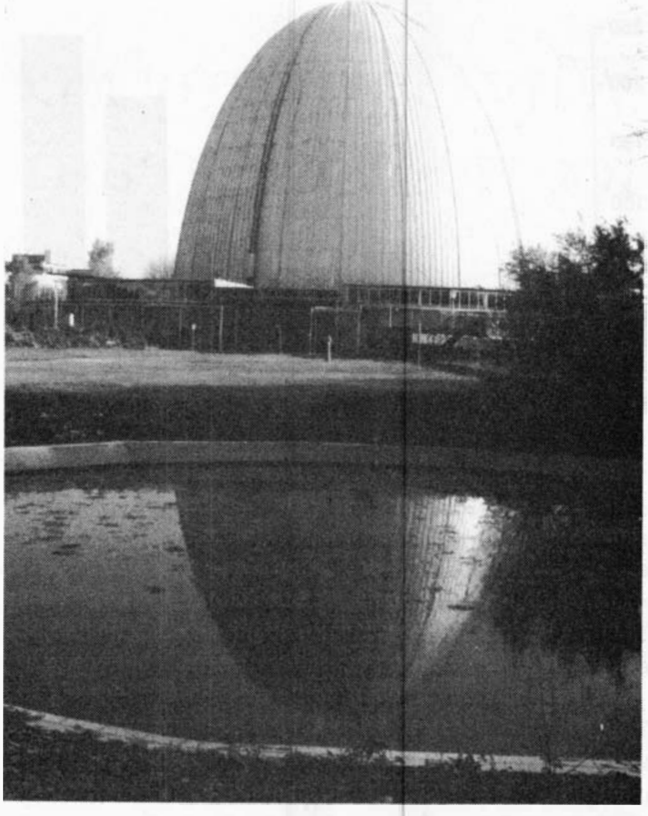
The same procedure is applied to seek out flaws in materials or in machine building to check the cooling ducts in turbine blades. Neutrons are perfectly suited for this, because they can easily penetrate metals, but are very sensitive to hydrogen and do not leave any energy in the object penetrated, so that virtually no disruption occurs. This is important also in the field of art for the inspection of oil paintings, which is being done at the research reactor of the Hahn Meitner Institute in Berlin.

Another way to use neutrons is to measure the change of energy and direction of neutrons after they have passed through an object, which makes most minute movements of the atoms in an object visible. Since the wavelength of a neutron is as long as the radius of an atom, neutrons will only be reflected in one direction, if atoms are ordered regularly in the object tested. Thus, they will show the position of the atoms within a solid body. This has been decisive for the development of strong magnets used for magnetically levitated trains or computers.

Neutrons in biophysics

Nondestructive penetration using neutrons is critical in biophysical research, since unlike X-rays, with their much higher energy level, neutrons do not kill living tissue during micrography. There is no other method used in biophysics which can replace neutron beams, especially for looking at slow movements, such as the functions of enzymes or of receptors (homone receptors or antibodies), or the chemical-mechanical transformation of energy in muscles or the movement of cells.

This is where the "ultra cold" neutrons are used in experimental work. While thermal neutrons have a speed of about 2,000 meters per second (m/s), ultra cold neutrons move at a speed of only 5 m/s—about as fast as a person riding a bicycle. This is only one-tenth of a trillion parts of the energy the neutron had when it left the split atom. Indeed, they are so slow that they cannot move on their own against the force of gravity. In a reactor, they cannot be directed outward toward an experiment.



In operation since 1957, the old nuclear reactor at Garching, dubbed "the atomic egg," is urgently in need of replacement.

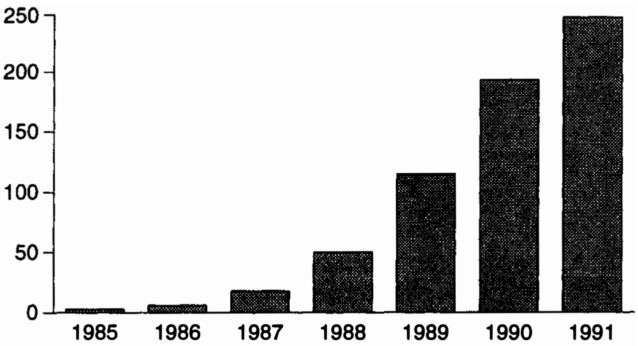
In Garching, two ways have been developed to make use of them. One way is to direct a neutron beam at copper mirrors rotating around a wheel 1.7 meters in radius. The neutron beam will be reflected, while the neutrons will lose most of their energy. A continuous flow of ultra cold neutrons develops that can be directed for use in an experiment. The wavelength of ultra cold neutrons is a thousand times as long as that of thermal neutrons, and is especially well-suited for testing interference and bending effects.

With the help of dispersion experiments with neutrons, biology and biophysics are on the threshold of a new revolution. Experiments at the most powerful neutron generator of Europe, in Grenoble, have been crucial in deciphering the

FIGURE 1

Growth in the number of cancer cases treated by neutron irradiation at Garching

(number of patients)



Source: Technische Universität München.

structure of ribosomes, which synthesize proteins in the human body. These experiments take advantage of the sensitivity of neutrons to hydrogen, a sensitivity which is enhanced by replacing light hydrogen atoms with heavy ones (deuterium). The much enhanced dispersion effect produces a much clearer image of the structure of the protein complex.

This "deutering" using modern methods of molecular biology works for several of the 20 amino acids. With the aid of neutron bending one obtains a high-contrast image of the changes both in the structure of proteins and in the function of enzymes during the mutation of individual amino acid molecules. These experiments aim at making visible the synthesis of proteins, which occurs at membrane-bound ribosomes, by inserting deutered amino acids.

Cancer therapy

Another pioneering field is the use of neutron beams in cancer therapy. Neutrons were used as early as 1938 by Robert Stone to irradiate tumors, but the real breakthrough in this area occurred in the 1960s, especially at the Hammersmith Hospital in London. Since then, some 10,000 patients have been treated with neutron irradiation in about 20 cancer treatment centers around the world, and the numbers are growing because of its spectacular success. New neutron beam generators are necessary especially for these medical applications of neutron beams.

In treating various types of tumors, neutron beams have proven much more efficient than "conventional" gamma rays, especially for malignant tumors of the salivary gland, slowly growing sarcomas, several forms of bone cancer, and advanced tumors of the prostate gland, intestines, skin, and eye, ear, nose, and throat. (See **Figure 1.**)

The efficiency of this kind of treatment depends on the amount of oxygen in the tissue, which in turn depends on blood circulation. Other factors are the speed of growth of the tumor and the ability of the tissue to recover after treatment.

All of these factors are much less affected by neutron radiation than by gamma rays, which means that neutron radiation can be six or eight times more efficient biologically.

Of all neutron beams presently used for therapy, the converted neutron beam at the FRM in Garching, using fast neutrons with an energy measured in MeV, has the highest biological efficiency and is least dependent on oxygen supply in the tissue. It is especially well-suited for treatment of tumors that grow back after conventional radiation treatment, chemical therapy, and/or surgery, since the initial treatment of such tumors often impairs blood vessels, making tumor cells less sensitive to conventional radiation treatment than the first time around.

Yet another new area of basic medical research is being pursued at Garching: neutron absorption therapy. Special boron compounds are inserted into the tumor and irradiated with thermal neutrons. These low-energy neutrons are absorbed by the boron atoms inside the tumor, causing the atoms to decay, which in turn releases short-range radiation. Since the boron is concentrated within the tumor, radiation will only affect the tumor, and not healthy tissue.

Neutrons in semiconductor technology

Most important for all areas of silicon semiconductor technology, is the careful doping of silicon with other elements such as boron or phosphorus. Using what is called neutron transmutation, silicon can be spread very precisely and homogeneously over the crystal. This will be of utmost importance for the technology for regulating high-voltage installations such as power plants or the propulsion technology for magnetically levitated or other high-speed trains. This technology is based on the fact, that an isotope of silicon, ^{30}Si, is transformed into phosphorus when it absorbs a neutron.

Perhaps these advances in exploring neutron radiation will help turn around the fierce debate on nuclear energy. If ever more stringent regulation is imposed on nuclear research, chances for the construction of new research reactors—and they will be necessary for the irradiation of silicon—are virtually zero.

On the other hand, halting basic research in this area, with its many applications, will cause irreparable harm to the industrial strength not only of Germany, but other nations as well.

We can only hope that the German courts will uphold the decision of the district government of Upper Bavaria, which ruled that the positive effects of a new reactor for neutron research at Garching have "a greater weight" than "interests of nature and the landscape." The ruling says that "this project is of great importance for the further development of science in Bavaria, and for the competitiveness of the affected industries and trades."