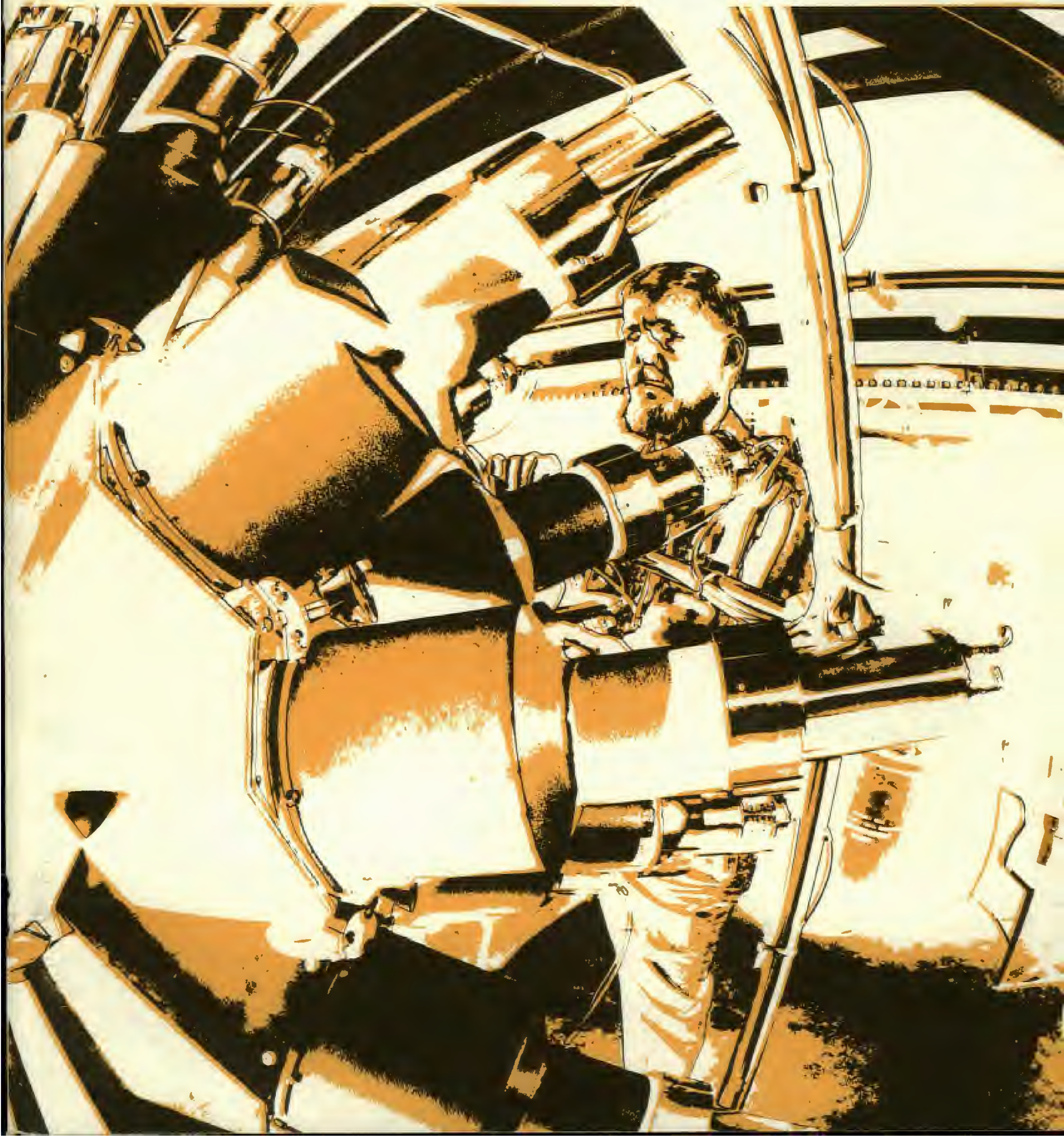
Oak Ridge National Laboratory

review

Fall 1980



THE COVER: Recently installed in the Holifield Heavy Ion Research Facility is this spectacular device, the Spin Spectrometer here being viewed by David Hensley. It is described in detail by its mentor, Mel Halbert, on p. 34

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VOLUME 13 NUMBER 4 **Fall 1980**

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The *Review* is published quarterly and distributed to employees and others associated with the Oak Ridge National Laboratory. The editorial office is in Building 4500-North, Oak Ridge National Laboratory. P.O. Box X, Oak Ridge, Tennessee 37830. Telephone: Internal 4-7183; commercial (615) 574-7183; FTS 624-7183.

ISSN 0048-1262

OAK RIDGE NATIONAL LABORATORY
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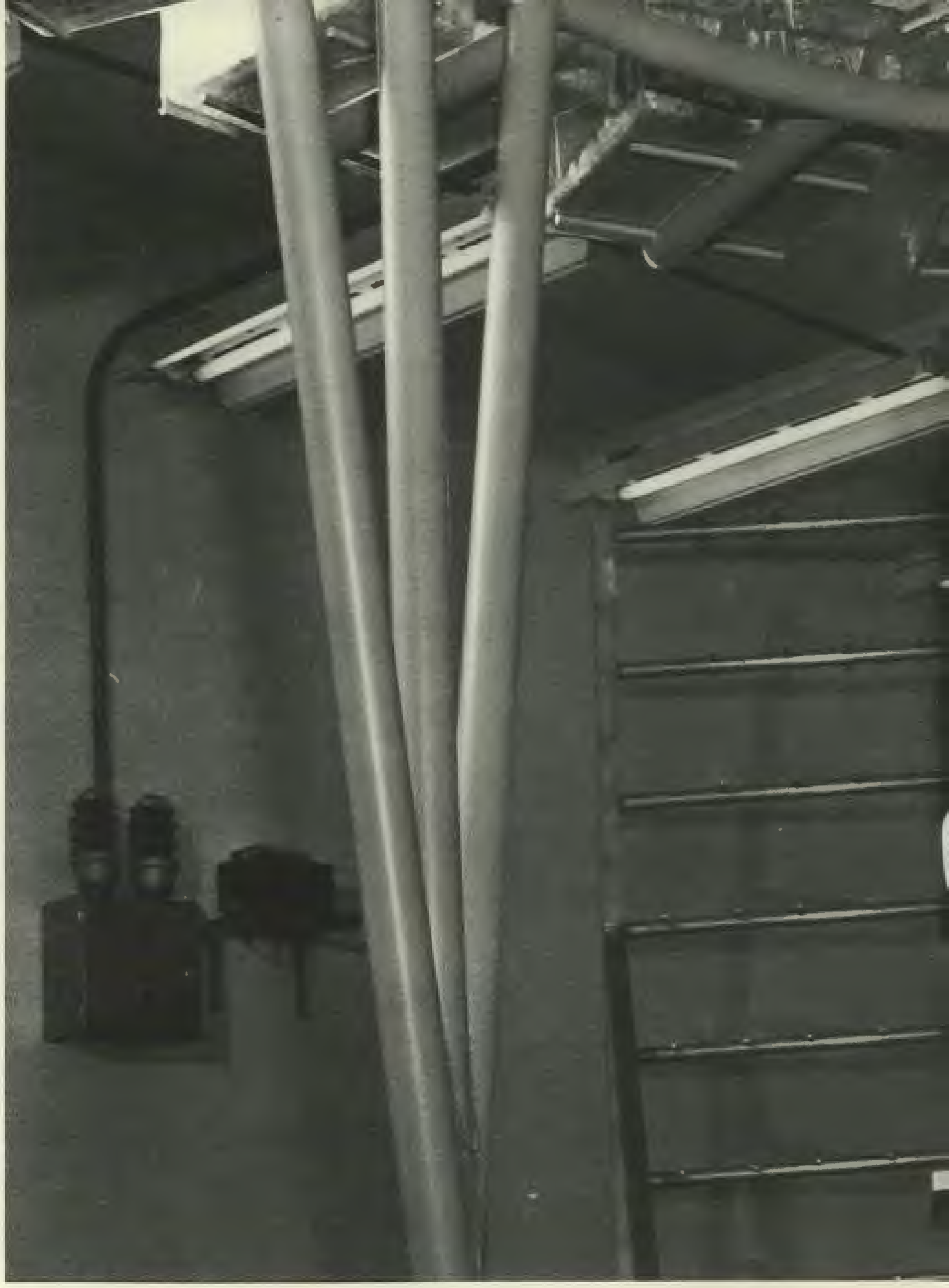
In this 1955 photo, Bill and Lee Russell check a possibly mutant mouse in one of the 66 rooms of the famous ORNL mouse house.

Of Mice and Mutagens

Liane Brauch Russell, a native of Vienna, Austria, has been head of the mutagenesis and teratogenesis section of the Biology Division since 1975. She holds an A.B. in chemistry from Hunter College in New York City and a Ph.D. in zoology and genetics from the University of Chicago. Before working on her doctorate, Lee was a research assistant at Jackson Memorial Laboratory, where she met her husband. In 1947 she came to ORNL to work on research projects in mammalian genetics and mutagenesis. She has been appointed to committees of several prestigious organizations, including the National Council on Radiation Protection and Measurement and the National Academy of Sciences. She has won many awards, including the *Atlantic Monthly* national essay prize in 1942, a *Mademoiselle* Merit Award for outstanding woman in 1955, and the International Roentgen Medal in 1973. In 1979 she was elected to the Hunter College Hall of Fame. She and her husband have been active leaders of the Tennessee Citizens for Wilderness Planning, which aims at protecting wilderness and scenic rivers from the ravages of strip mining and dam building.



The Story of the Russells

By CAROLYN KRAUSE

When William Lawson Russell arrived in Oak Ridge in November 1947, he was already an outstanding geneticist, but a disaster forced him to rebuild his distinguished career from scratch. A fire in a peat bog near Bar Harbor, Maine, had broken out of control the previous month, burning down a third of the city and virtually all of Jackson Memorial Laboratory, where Bill had worked for ten years. The conflagration destroyed the British-born geneticist's records, unpublished data, and, perhaps worst of all, most of the special strains of mice he had carefully bred for his experiments.

A former consultant for the Manhattan Project, Bill had accepted a job offer in the fall of 1947 from what was then Clinton Laboratories in Oak Ridge. He was waiting for his clearance from the Federal Bureau of Investigation when the October fire threatened Bar Harbor. Bill and his young wife Liane, who was working on a doctorate in genetics at the

Bill Russell, an ORNL consultant since 1977, was the scientific director of the mammalian genetics section of ORNL's Biology Division from 1947 to 1975. A native of Newhaven, England, he earned a B.A. in zoology at Oxford University in 1932 and a Ph.D. in zoology and genetics five years later at the University of Chicago. He worked as a research associate at Jackson Memorial Laboratory in Bar Harbor, Maine, from 1937 to 1947, when he came to Oak Ridge. His outstanding work in mammalian genetics and mutagenesis has brought him many honors, including the Fermi Award in 1976, the Distinguished Service Award of the Health Physics Society in 1976; and the International Roentgen Medal in 1973. He is a member of the National Academy of Sciences and has served on many committees and task forces of organizations setting standards for radiation protection. He has been president of the Genetics Society of America. The story of his and Lee Russell's remarkable work in radiation and chemical mutagenesis through studies of mice is told in the following pages.

University of Chicago, joined a group of volunteer fire fighters who managed to keep the fire under control for a few days. Because women were not allowed on the fire line, Lee had to disguise herself as a boy so that she could help battle the blaze. She was beginning her reputation as a woman who steps boldly into areas where men usually tread.

It was because of Lee that her husband accepted a position in Oak Ridge. Bill was thinking of leaving Jackson Memorial Laboratory for personal reasons and was looking for a university that would offer positions to both him and his wife. Brown University had offered him a position but balked at employing husbands and wives together in the same department. Then Bill received a job offer on Monsanto stationery from Alexander Hollaender, director of the new Biology Division at Clinton Laboratories, which was operated by the Monsanto Chemical Company of St. Louis for the new

Atomic Energy Commission.

Bill did not respond to the offer because he was not seeking what appeared to be an industrial research position. But when Hollaender called and persuaded him that Clinton Laboratories had a university atmosphere and informed him that Monsanto would be replaced by the University of Chicago as contractor, Bill grew more interested. And when Hollaender promised a position to Lee even before she had her Ph.D., Bill could resist no longer. He accepted Hollaender's offer.

Hollaender, former director of the radiobiology laboratory at the National Institutes of Health in Bethesda, Maryland, was preparing to move his staff from temporary housing near the Graphite Reactor at X-10 to several large, unused buildings that had been hastily constructed at Y-12 in 1945 for chemical extraction of uranium-235. His original research plan for the division was to focus on "the basic aspects of the effects of radiation on living cells." Hollaender himself had done some outstanding basic research at NIH using ultraviolet radiation on fungi; from his studies, he correctly suggested in 1939 that the nucleic acids, not the protein in the cell, carried the genetic information in reproduction. Hollaender initially concurred with the prevalent view that DNA is DNA—that is, if you understood the radiation effects on the molecular basis of heredity in simple cells, then you could deduce the effects of radiation on more complex organisms such as mice and men. Thus at Oak Ridge early emphasis was placed on studies of radiation effects in microorganisms and in the chromosomes of the spiderwort *Tradescantia* and the fruit fly *Drosophila*.

Fruit Fly Research

Fruit flies, first used for genetic research by Columbia University zoologist and Nobel laureate Thomas H. Morgan in 1906, offered several advantages as subjects for genetic study, one of which is their easily observed inherited characteristics. In 1927 Herman J. Muller, once a member of Morgan's research team, demonstrated that he could increase the rate of mutations in fruit flies by exposing them to x rays. He found that, by irradiating fruit flies and mating them, he could produce offspring that exhibited such readily observed mutations as altered eye color and oddly shaped wings. For this discovery Muller earned the Nobel Prize in medicine and biology in 1946 and emerged as dean of American geneticists.

When Hollaender heard from the editor of the *Journal of Heredity* that Bill was thinking of leaving Bar Harbor, Hollaender began to reconsider his stance on genetic research at Oak Ridge. Bill, who had participated, in the Manhattan Project, on some pioneering work on the effects of radiation on mice, was convinced that mouse experiments on a very large scale would yield significant data on the mutagenic effects of radiation—data that could be applied to understanding what radiation can do to the genes of other mammals, including man. Furthermore, the AEC was interested in reviving the mouse genetics work that had been conducted during the war to help determine radiation tolerances for employees at nuclear energy facilities. Hollaender was eager to capitalize on this new initiative, although a large mouse project would be risky and costly.

According to Richard G. Hewlett and Francis Duncan, authors of *Atomic Shield, 1947–52* (second volume of *A History of the U.S. Atomic Energy Commission*),

"Hollaender liked long shots and he believed in Russell's ability. He found added reason for confidence in discussions with Sewall Wright, Russell's mentor and professor of genetics at the University of Chicago. ... Muller was slower than Wright to appreciate the possibilities of Russell's proposal, but he too eventually gave his support." Hollaender persuaded the AEC to support the project and hired Bill to set up a large mouse program in Oak Ridge.

The Mouse House

At Oak Ridge, Bill had to beg mice in a time of stiff competition because of the disaster at Jackson Memorial, one of the world's largest mouse laboratories. In addition, he spent a year and a half designing the cages, food containers, racks, bottle-washing devices, and other innovative equipment required to accommodate the tens of thousands of mice that he would have once his colony grew.

"I tried to organize the mouse laboratory to save labor and money," says Bill. "For instance, we modified a machine for washing soft drink bottle crates into an automatic cage-washing machine. We kept mice in wooden boxes in the early days and then switched to plastic cages when they became cheaper and more durable.

"We have one of the most inexpensive of mouse operations and yet have had excellent success in control of disease. We have never had an epidemic. We breed our own animals and only rarely bring in outside mice, when, for example, we need a gene not available in our colony. Then we run the outside mice through a rigid quarantine. Once it is established that the outside mice are disease free, then we let them into our regular animal rooms."

The mice in the Biology Division are housed in small rooms on three floors. "If disease broke out," says Bill, "we would isolate mice by room or floor to prevent the disease from spreading to other mice. It's a policy that has paid off."

Today, the mouse house has 66 rooms, each with 1000 cages. The cages contain either mice of the same sex or a breeding pair, often with a litter. The total number of mice ranges from 300,000 to 400,000. The ORNL mouse laboratory, one of the largest in the world, is a national resource.

The Russells in the mouse house 25 years ago.

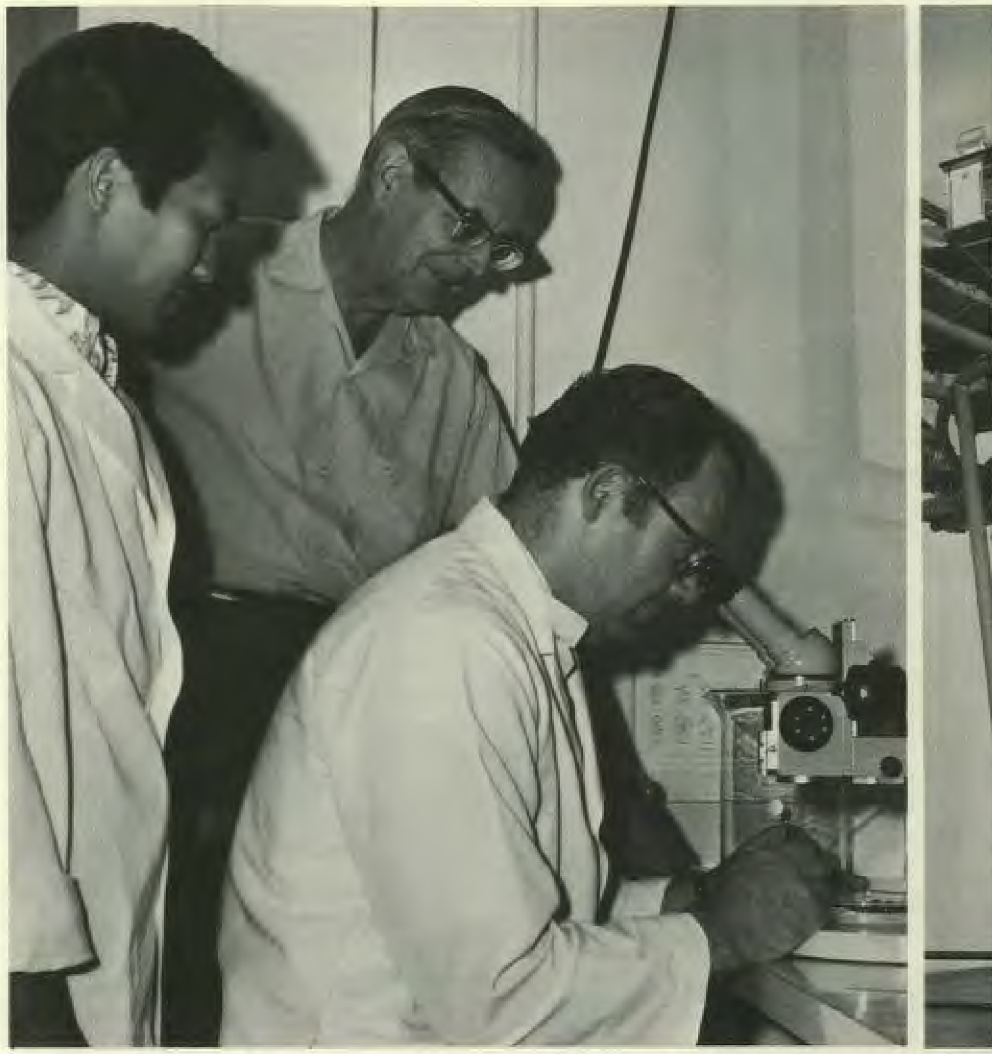
Radiation and Embryos

While Bill was getting the mouse house in order in 1948, Lee was completing her doctoral dissertation and devising new experiments. Her first idea was to develop a spot test to measure somatic mutation rates in mice. Her approach was to irradiate the pregnant mouse at that point in embryo development when the cells determining coat color were being differentiated. She reasoned that embryonic cells destined to specialize in the production of pigment would be multiplied as a result of cell division. Thus, genetic damage to a single such cell in the embryo would be manifested as a conspicuous splotch of different color in the coat of the mature offspring, provided the embryo carried appropriate coat color genes. A black mouse that carried a recessive (normally nonexpressed) gene for brown, for instance, might show a brown spot of fur if the covering gene were mutated or destroyed.

In the course of irradiating different stages of embryonic development to determine which was optimum for mutation induction that would result in visible spots, Lee found newborn mice with a great assortment of malformations. She therefore temporarily abandoned her efforts to develop the spot-test method (it was finally published in 1957 and has since been revived by her for chemical mutagenesis work; see below) and concentrated on the intriguing problem of radiation effects on embryonic development.

Scattered work in that area of research had been done in the past, but early investigators had paid scant attention to exact embryonic stage. Some publications, for example, simply reported that "pregnant females" were irradiated. Lee systematically studied stages separated by 24-h intervals, starting from the day of conception. Irradiation with some doses at some stages caused rapid

In this 1968 photograph, Bill Russell and Bob Cumming at the microscope are intrigued by an abnormal mouse embryo discovered by Waldy Generoso.



death of embryos, but the surviving embryos were allowed to develop to birth, at which time the baby mice were weighed, measured, observed for external and internal abnormalities, and finally processed for detailed skeletal study.

When all the results were tabulated, it became apparent that the effect of radiation was strictly dependent on the stage of development irradiated. Each stage produced its own characteristic assortment of effects. Lee found that when radiation is administered early in development, before the embryo implants in the uterus, there is an all-or-none effect: embryos either die very rapidly, or they appear to be totally unaffected and develop into normal mice. When radiation is given a little later, the chance of prenatal killing decreases, but the mice may be born with malformations. This is particularly true for radiation administered during the period when major organ systems are being laid down (6 to 13 days after conception, in the mouse).

The exact type of malformation is dependent on the stage of development (within that broad period) that is irradiated. For example, rib fusions are induced only by irradiation on day 7½, and curvature of arm or leg bones only by irradiation on day 10½. The number of ribs can be increased by irradiation on day 8½, but decreased by irradiation on day 11½.

In human prenatal development, the period when major organ systems are being laid down, which is, by analogy with the mouse, most susceptible to the induction of malformations, is day 10 to week 7 after conception. In 1952, the Russells published an article in the *Journal of Radiology* that summarized cases of human abnormalities that had been reported in the medical literature following irradiation of pregnant women. In one case, in which exact information was available on the stage irradiated, the resultant arm abnormalities in the baby were exactly what would have been predicted from the corresponding stage in the mouse. The Russells realized that most physicians were aware that it was hazardous to irradiate pregnant women. The problem, as they saw it, was that some of the most sensitive embryonic stages occurred at a time when some women might not yet know that they were pregnant.

The Russells therefore recommended in the 1952 article that, if it was possible to do so without jeopardizing the health of the women, diagnostic irradiation involving the pelvic region of women of childbearing age should be scheduled so as not to occur more than two weeks after the last menstrual period. Since conception usually occurs halfway between periods, the two weeks following the beginning of the last one are unlikely to involve an unsuspected pregnancy.

This recommendation

Elizabeth Kelly checks mice that are about to be exposed continuously for several weeks to gamma radiation from a cesium-137 source.

stimulated some heated letters from physicians to medical journals, protesting that mouse results should not be extrapolated to human beings. However, it was eventually adopted by the National Council on Radiation Protection and Measurements and the International Commission on Radiological Protection, two standards-setting bodies that have been in existence since the 1920s. Many physicians continue to abide by the rule today, although a few consider the scheduling procedure to be an unnecessary inconvenience, arguing that recent improvements in x-ray and fluoroscope equipment have so lowered diagnostic doses as to make them safe even for embryos. Not all scientists agree.

In 1955 Lee described her studies on mouse embryos in an important talk at the First United Nations International Conference for Peaceful Uses of Atomic Energy, held August 8 through 20 in Geneva, Switzerland. In her talk she outlined the critical periods and the relationship between radiation doses and abnormalities produced at different stages of embryonic development. It is noteworthy that Lee was the only woman in the official U.S. delegation to this first "Atoms for Peace" conference.

Specific-Locus Method

In the wake of the atomic bomb's destruction of Hiroshima and Nagasaki, many questions arose about radiation. Answers to the questions were sought out of concern for the Japanese survivors of the World War II bombings and for the general public whose exposure to radiation was increasing because of fallout from aboveground atomic bomb tests in the 1950s as well as from increased use of x rays and radioisotopes for diagnostic tests and therapy. In the late 1960s and all of the 1970s the public grew apprehensive about low-level radiation emitted by operating nuclear power plants.

Key questions unanswered at the end of World War II were these: How much radiation is required to produce adverse health effects, such as cancer and genetic damage? Does the extent of the damage differ with the type of radiation (gamma rays, x rays, alpha and beta particles, or neutrons)? Is the outcome affected by whether the radiation exposure is delivered over a short or a long period of time? Does low-level radiation cause proportionally low health effects, or is there a level of exposure (threshold) below which no health effects are perceptible? These are some of the important questions that Bill tried to answer in his experiments with thousands of mice.

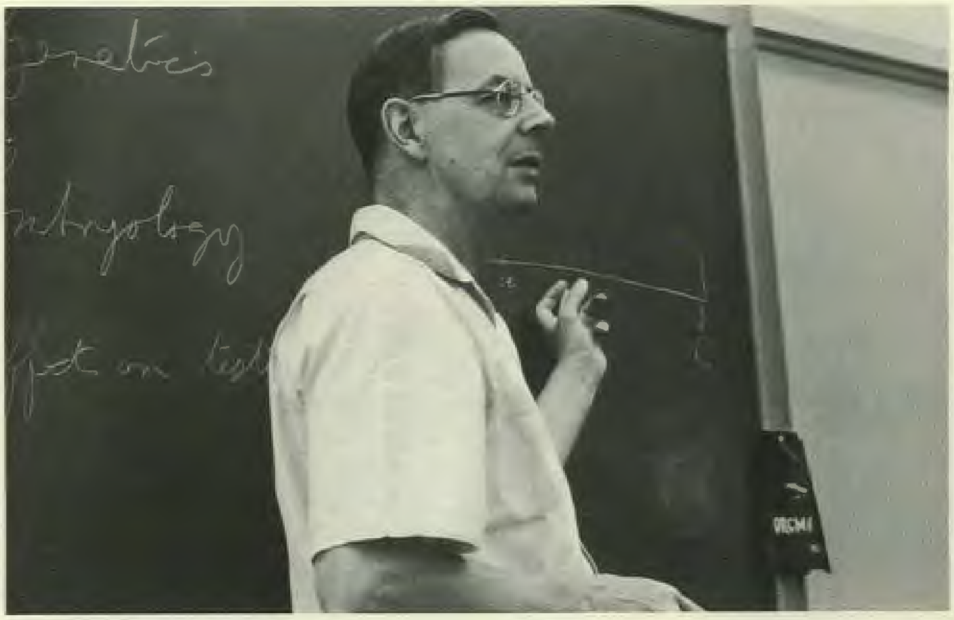
Bill's goal in 1948 was to determine the rate of gene mutations in mice exposed to radiation at sublethal levels. It was already known that radiation could cause chromosomal damage in mice that could be transmitted to descendant generations. Virtually nothing was known, however, about the induction of gene mutations in any mammal.

To find out the gene mutation rate, Bill devised the specific-locus method which permitted him to measure mutation rates in certain genes located at specific points, or loci, in the mouse chromosomes. He selected seven genes that produced easily recognizable traits. Six of the genes determined coat color and the seventh governed ear size.

To carry out the experiment, Bill had to breed a strain of mice possessing the seven traits as recessives to the dominant character in the normal, or wild-type, mouse. For the seven genes, the dominant traits manifested in the normal male mouse are a uniformly dark coat color and normal-sized ears, whereas the recessive traits combined in the special strain of mice produce an almost white coat color and short ears.

According to Bill's reasoning, exposing the wild-type mice to x rays would occasionally convert the dominant allele (form of gene) to the recessive allele of any of the seven genes under study. If a

Bill Russell outlines research plans for the mammalian genetics and development section in the late 1950s.



mutated germ cell (the spermatagonium, which generates spermatocytes that in turn give rise to spermatids and sperm) from a wild-type mouse combines with one from a mouse already possessing the recessive trait, the resultant offspring will be born with the visible recessive trait—altered coat color or short ears. In some cases, the radiation may destroy a gene or cause deletion of a piece of chromosome. These events will also be detected by the specific-locus method when they involve the marked loci. Thus, a mutation rate could theoretically be worked out for mice exposed to x rays.

Radiation Mutates Mice

While waiting for his mice to proliferate in 1950, Bill did some pilot tests with the available mice and determined that a large experiment could give a reliable measure of the mouse mutation rate. The next year showed that this expensive, time-consuming experiment was paying off. According to Hewlett and Duncan, "Preliminary results in the main experiment enabled Russell to report in the summer of 1951 that examination of over 48,000 mice, whose sires had been exposed to 600 roentgens of x irradiation, showed more than 50 mutations at five of the seven loci. Among the almost 38,000 mice in the control experiment, in which no radiation was used, only two mutations at the specific loci had been found."

Bill's successful experiment had, for the first time, measured a radiation-induced mutation rate in a mammal. Since the radiation exposure limits at that time were based on *Drosophila* mutation rates, it was obviously important to compare mouse and *Drosophila* mutational sensitivity. In order to obtain an accurate comparison, Bill sponsored a *Drosophila* study by Mary Alexander at ORNL that used a comparable specific-locus method and tested the same germ cells, the spermatogonia. In this comparison, the mutation rate in the mouse was 15 times as high as that in the fruit fly. The finding was significant and influential in standard setting.

"It made our work easier, but it was a scare for man," says Bill. "The results showed that mutation rates are different in various species and that studies of radiation-induced mutations in mice were necessary. Shortly after this finding the NCRP reduced the permissible levels for occupational exposure to radiation by a factor of 3."

Bill agreed that the new exposure limit should not have been reduced by a factor of 15 because the *Drosophila* data on which the old limits had been based came from experiments on sperm, which were shown to be five times as sensitive to mutation induction as spermatogonia. Bill's work had been done with spermatogonia because these are the reproductive cells that receive the major portion of the radiation dose genetically significant to the human population.

In later experiments, Bill tried different levels of high radiation doses, dropping down to 300 R. But even at 300 R many of the male mice were temporarily sterilized, suggesting that radiation had killed spermatogonia in large numbers. Studies by ORNL's Gene Oakberg confirmed this. So Bill decided to switch to low dose rate experiments—that is, to deliver the total amount of radiation over an extended period of time instead of all at once. Subsequent experiments showed that subjecting mice to radiation at low dose rates killed far fewer spermatogonia than did the same dose at high dose rates.

Acute vs Chronic Radiation

Continuation of the low dose rate experiments led to a revolutionary finding in radiation genetics in 1958. The Russells and Elizabeth

Lee Russell in 1957 points to cages arranged on curved racks for gamma-ray exposure.

M. Kelly discovered that the mutation rate in mice exposed to chronic radiation was from one-third to one-fourth the mutation rate in mice exposed to acute radiation. For example, mice exposed to 600 R administered over a period of six weeks experienced a much lower mutation rate than mice exposed to 600 R in a few minutes. Says Bill, "The discovery that radiation delivered at low dose rates produces fewer mutations in mice than does the same total dose delivered at a high dose rate suggested the existence of a repair mechanism previously unsuspected."

The 1958 discovery was one of the Russells' most famous findings because it contrasted markedly with results in *Drosophila.* Before publishing their results, the Russells communicated with Muller by telephone. Muller was skeptical of the Russells' results and tried to find errors in their work, because no dose rate effect had been found in fruit fly studies. But finally he agreed that the ORNL work was valid and congratulated the Russells and Kelly on finding a major genetic principle that had been overlooked in *Drosophila* experiments. The dose rate effect in mice was reconfirmed at ORNL and at Harwell Laboratory in England, but Muller never did find a dose rate effect after several years of experiments on *Drosophila.*

X and Y Chromosomes

Higher organisms have within the nucleus of each cell several pairs of chromosomes (23 pairs in man, 20 in the mouse, and 4 in the fruit fly), threadlike bodies on which genes are arranged in linear fashion. All but one of these pairs are found in both males and females of a given species and are collectively named autosomes. The remaining two chromosomes are the sex chromosomes. In the fruit fly, as well as in mice and human beings, normal females have two identical sex chromosomes, XX, whereas males have one X and a different sex chromosome, named Y, so that they are XY. In the fruit fly it had been discovered some time ago that sex determination was a result of the relative numbers of Xs to autosome sets (abbreviated A) and was independent of the Y chromosome. Thus, not only is 2A + XX a normal female, but, by genetic manipulation, one can construct a 2A + XXY fly that is also female; similarly, 2A + XY (normal) as well as 2A + X (constructed) are males. Until 1959 it was not known whether sex determination in mammals, including mice and human beings, followed this same mechanism or a different one.

Lee developed stocks of mice that carried marker genes, such as *Ta*, on the X chromosome. Female mice carrying *Ta* on one of their two X chromosomes and the normal counterpart, +, on the other chromosome (and thus designated $X^{Ta} X^{+}$) resemble tabby cats, with transverse stripes of black on the usual tan background. Male mice of the type $X^{Ta}Y$ have, instead, a black streak down the length of their backs and spreading over most of their bodies. Lee found occasional exceptional animals in the stock, namely, males with transverse stripes and females with the longitudinal streak. By experimental breeding and deductive reasoning, she concluded that the exceptional males were $X^{Ta}X^{+}Y$ and the exceptional females $X^{Ta}0$ (0 = zero, i.e., the absence of a second X). Therefore, unlike the situation in the fruit fly, it was not the number of Xs but the presence or absence of a Y chromosome that determined sex.

At about that time new cytologi cal techniques had become available by which chromosomes could be counted under a micro-scope. Lee's coworker Bill Welshons was thus able to verify her genetic deductions by direct observations of chromosomes. The

Oak Ridge team published its conclusions about the male-determining nature of the mouse Y chromosome in 1959. Soon thereafter, British investigators found, on the basis of cytological evidence only, that in man, too, the XXY condition was male and the X0 condition female.

The radiation experiments at Oak Ridge produced not only specific-locus mutations but also occasional gross rearrangements between chromosomes. Working with certain such rearrangements in which the X and an autosome had exchanged parts, Lee found that, in many cells of the body, the action of genes on the autosomal portion of the newly juxtaposed chromosomes was suppressed by the proximity of X-chromosomal material. However, this happened only if the equivalent of two Xs was present in the animal, that is, in XX females or XXY males, but not in XY males or X0 females. This finding led her to hypothesize that, in mammals, only a single X chromosome is active in any given cell of the body; when two Xs are present (e.g., in a normal female), genes on one of the Xs (as well as on part of any autosome that may be attached) are not active in producing gene products. This hypothesis, published in 1961, was thus the indirect result of a radiation-mutagenesis experiment. (Mary Lyon of Harwell independently, and on the basis of other evidence, proposed a similar hypothesis in the same year.) The single-active-X hypothesis led to widespread research on the nature of the phenomenon, and the inactivation of certain chromosomal segments in XX mammals has become an excellent tool for the study of gene action.

Is There a Threshold?

Many scientists who have studied radiation's genetic effects on living organisms subscribe to the linear hypothesis, which states that risk of induced damage is directly proportional to radiation dose. In other words, 5% of a given dose should theoretically cause 5% as much risk to health as the risk at full dose, and there would be no threshold dose—that is, no exposure level below which no adverse effects are observed. The Russells' finding of a dose-rate effect suggested that a threshold might be possible if the repair mechanisms evidenced by the dose-rate effect were capable of eliminating all damage from low-level radiation.

In 1965 Bill found a possible threshold in female mice. He and his colleagues had been studying the effect on male mice of low radiation dose rates ranging from less than 10 R/week to 0.8 R/min. They found no further reduction in mutation frequency over this range of dose rates. Thus, there is apparently no threshold dose rate in males. When they switched to studies of female mice, they first collected data from irradiated maturing and mature oocytes, namely, those germ cells going through the final six weeks of maturation before ovulation. At a dose rate of about 100 R/week, the lowest one tried, Bill found that the effect is so minimal that "for practical purposes you can say there is a threshold for the female."

The results were even more dramatic when the studies were

Elizabeth Kelly, now retired, shows a mutant mouse to visitors at the 1962 open house at the Biology Division. Martha Larsen and Jean Bangham are to her right.

extended to the arrested oocyte. Oocytes reach this stage at the time of birth in the mouse and before birth in the human. They remain in it throughout most of the reproductive lives of mouse and human females and leave it only when they start the final maturation stages before ovulation. Therefore, the arrested oocyte is the stage of the greatest importance in human exposure. The surprising result in the mouse arrested oocytes was that no radiation dose, even at high dose rates, produced any elevation of mutation rate above the spontaneous level. This result was obtained with both x-radiation and gamma radiation, and even with neutrons. (Neutron radiation was a significant component of the blast from the Hiroshima bomb).

Further evidence of the ability of female germ cells to resist or repair genetic damage surfaced in 1979 when Waldy Generoso and his associates in the Mammalian Genetics Section (headed by Lee) showed that eggs in some strains of mice are able to repair damage in sperm that would cause mutations in offspring. Thus, male mice exposed to certain chemical mutagens and mated with females with this special capability still have normal offspring.

Hycanthone Controversy

In the late 1960s the Russells began studies of the genetic effects of chemicals on mice. One of the early studies took place in response to a request from the World Health Organization, which was concerned that a drug used to combat a common disease in many underdeveloped countries had been found mutagenic in a screening test using bacteria. WHO wanted to know if the drug was mutagenic in mice.

The drug hycanthone is used to combat schistosomiasis, a debilitating and sometimes deadly disease prevalent in Africa, Asia, and South America. (About 80% of all Egyptians have had it sometime during their lives.) The disease is caused when a male and female parasitic worm in permanent intercourse enter the human body and lay thousands of eggs that block blood vessels. WHO had recommended the use of hycanthone because it is easy to use and effective; while some drugs have to be taken orally and repeatedly for a period of time, a single injection of hycanthone can bring the disease under control.

But in 1970, a laboratory using the Ames test (developed at Berkeley) found that hycanthone is mutagenic in *Salmonella* bacteria. The finding made the headlines, and newspapers carried articles suggesting that hycanthone might cause cancer because mutagenic agents are often found to be carcinogenic. So WHO asked Bill to test hycanthone in mice in hopes of determining whether the drug could be a genetic hazard in man.

Using the specific-locus test, Bill found that hycanthone produced no genetic effects in male mice at 50 times the human therapeutic dose. Later both Generoso and Bill found evidence of chromosomal damage in female mice injected with 50 times the therapeutic dose. The effect was limited to oocytes in the last five days of maturation, and it dropped rapidly when the dose was lowered and when the route of injection was changed from intraperitoneal to that used in humans, namely, intramuscular.

In a 1971 paper, Bill and his colleagues estimated that the mutation rate from hycanthone at the human therapeutic dose would not, with 95% confidence, exceed 6% of the spontaneous mutation rate. "On the basis of our results," Bill says, "we could not recommend the elimination of hycanthone as a therapeutic drug for schistosomiasis."

Hycanthone, in combination with other health measures, has since been claimed to have wiped out schistosomiasis in one of the West Indies.

Skeletal Damage

In addition to the data on specific-locus mutations and the information on radiation-induced chromosomal aberrations obtained by other members of the Mammalian Genetics Section (which Bill headed for 28 years), knowledge was needed on the detrimental effects of mutations—the actual nature of the anatomical disorders caused by them. In 1960 Bill collaborated

The Russells examining a mouse last summer.

with one of the members of his group, Udo Ehling, in setting up an attempt to measure radiation-induced mutations affecting one of the major body systems in the mammal, namely, the skeleton. Ehling's experiments were successful, and Bill urged the use of these findings by committees involved in risk estimation. There was resistance to these findings because the animals were killed for observation of their skeletons, and there was, therefore, no unequivocal proof, by breeding tests, that the defective animals were true mutants.

Bill was convinced that the evidence for this was good, and he later persuaded his graduate student Paul Selby, who was headed for postdoctoral work with Ehling (now in Germany), to pursue the skeletal investigation further. Selby and his wife made an extensive study, similar to that of Ehling, but, by raising offspring from all animals that were to be killed for skeletal examination, they were able to prove by breeding tests that the skeletal defects scored by them were truly the result of mutations.

Selby's results now form an important part of genetic risk estimates made by the United Nations Scientific Committee on the Effects of Atomic Radiation and by the U.S. Committee on the Biological Effects of Ionizing Radiation of the National Academy of Sciences in their just-published report. An estimate of the amount of damage to all body systems was made on the basis of the proportion of mutations in humans that affect the skeleton. Extrapolation of the risk from the high doses and dose rates used in the skeletal studies to low-level radiation was made on the basis of Bill's specific-locus results. Selby, now back in ORNL's Biology Division, is continuing this work.

Genetic Risk Lower than Thought

In 1972 Bill stated that the genetic risk to human beings from low-level radiation exposure is about one-sixth of that estimated when the original health guidelines were set limiting permissible radiation exposures to the population.

"Our results from low dose rate experiments indicated that the original risk estimates were high and that the guidelines are conservative. But because there is clearly some risk in the male at very low dose rates and because it was not unduly uneconomical to comply with stricter guidelines, the guidelines were not relaxed despite low dose rate data in the mouse."

The Russells' work on radiation effects in mice has brought them much recognition and honor. In 1973 they shared the International Roentgen Medal for "outstanding contributions to the progress of research and applied science based on Roentgen's discovery." Lee was the first woman and the youngest person to receive this prestigious award.

Also in 1973 Bill was elected to the National Academy of Sciences. In 1976 he received the Distinguished Achievement Award from the Health Physics Society, which cited "the work of a man who has contributed enormously and almost equally to fundamental radiobiology and the derivations therefrom of importance to radiation protection philosophy and standards." In the same year, Bill was named Oak Ridge's first Senior Research Fellow of Union Carbide Corporation, and later that year he was chosen for the prestigious Fermi Award.

The work on radiation effects continues, although there is an increasing emphasis on chemical mutagenesis studies using mice. Bill and his colleagues, who have established that neutrons are more damaging than gamma rays and x rays at low dose rates, are now looking at the effects of alpha particles and beta rays from

The Russells "proved that sensitivity to radiation differs not only between mice and fruit flies but also between the male and female mouse. They developed most of the currently available mammalian mutagenesis tests..."

internal emitters, such as plutonium and tritium. Plutonium is produced in light water reactors and breeder reactors, whereas tritium will be the chief source of radioactivity in fusion power plants. In an experiment done this year with plutonium (an alpha emitter), they have found that the genetic risk of plutonium is considerably less than expected.

"It appears that the somatic effects are more worrisome than the genetic effects of plutonium," says Bill. "We've been doing the work on genetic effects of plutonium because no data existed and the Department of Energy is convinced that results are needed for a solidly based estimate of risk."

Chemical Mutagenesis

In the 1970s ORNL and the other national laboratories broadened their mandate to help develop nonnuclear as well as nuclear sources of energy. The effect on ORNL's Biology Division was to broaden its mandate as well; it became concerned with the mutagenic, carcinogenic, and teratogenic effects of chemicals as well as radiation. Many of these chemical compounds are products or effluents from the liquefaction or gasification of coal and from shale oil processes under development in the United States.

Shortly after being named head of the Mutagenesis and Teratogenesis Section of the Biology Division in 1975, Lee began to adapt the spot test (which she developed 18 years earlier) to the screening of chemicals for mutagenic effects in mice. The test saves time and money because it provides information in five weeks using relatively small numbers of mice. Seven research laboratories (including ORNL) now employing this spot test have found that about two-thirds of the 25 chemicals tested are mutagenic in the mouse.

In developing the test, Lee had to find the optimum time for administering the test chemical to the pregnant mouse. She discovered that a mutagenic agent shows up best in the spot test if, at the time of application, the exposed embryo has about 200 cells that will eventually specialize in producing pigment. If one of those 200 embryonic cells is mutated by the chemical, its subsequent multiplication will produce an oddly colored spot covering about 1/200th of the skin area—large enough to be observed. The developmental stage when an embryo has 200 precursor pigment cells is day 10¼ after conception. Some chemicals are delayed in reaching the embryo because of metabolism in the mother's body, so in such cases administration must be correspondingly earlier.

Says Lee, "If we treated only 20 presumptive pigment cells in each embryo (i.e., exposed younger stages), we would have to work with ten times as many animals before we might see a spot. If we waited and treated embryos possessing 2000 pigment cells (i.e., older embryos), the spots produced would be too small to be detected. Thus, we had to find the precise development stage that would allow us to see mutations in a reasonably sized sample."

Some of the chemicals found to be mutagenic in the spot test are benzo[*a*]pyrene (found in coal-liquefaction products), ethyl methanesulfonate, methyl methanesulfonate, triethylenemelamine, procarbazine, mitomycin C, and ethylnitrosourea (ENU).

The spot test is a quick whole-mammal mutagenicity screen, which, if positive, is generally followed by more extensive tests designed to determine whether heritable gene mutations and chromosome aberrations are induced in reproductive cells. Lee reported on the role of whole-mammal genetic tests and on the battery of assays used during her presentation to President Carter, when he visited ORNL in May 1978.

ENU—A Super Mutagen

Many chemicals that are mutagenic in *Salmonella*, *Drosophila*, and other organisms are not mutagenic in mice in the specific-locus test on spermatogonia. For example, ethyl methanesulfonate, a potent mutagen in many organisms, shows no mutagenic effect in mouse spermatogonia, even though it does in postspermatogonial stages, and thereby demonstrates that it reaches the testis in active form.

Recently, Ehling (mentioned above as a member of Bill's lab) discovered that procarbazine and mitomycin C, two drugs used to combat Hodgkin's disease, are mutagenic in the mouse in the specific-locus test. Earlier, a postdoctoral researcher in Bill's group had found that triethylenemelamine is mutagenic as well. Of the several chemicals tested, these three were, until recently, the only ones found to be mutagenic in the specific-locus test, and their effect was not very strong. Says Bill, "The impression was developing that perhaps the mammalian testis was so efficiently protected against damage by chemicals that only weak or moderate effects would be found. The possibility also existed that the spermatogonia might be effective at repairing mutational damage."

Recently, at the urging of his friends in the field of *Drosophila* mutagenesis, Bill conducted an extensive study on diethylnitrosamine (DEN). Again the results were negative in mouse spermatogonia, although this compound is extremely potent in *Drosophila*. It was speculated that perhaps the enzymic activation of DEN occurred elsewhere than in the testis and that the product was not reaching the testis. This led to a test of ENU, which is also a potent mutagen in *Drosophila* and is believed to form the same reactive agent as DEN, but does not require enzymic activation. "What surprised us," Bill says, "is that ENU worked so fantastically in the mouse."

In the *Proceedings of the National Academy of Sciences* published in November 1979, Bill and his colleagues reported that the specific-locus test shows ENU to be the most potent mutagen ever tested in the mouse. His colleagues were Elizabeth Kelly, Patricia Hunsicker, Jean Bangham, Savanna Maddux, and Elizabeth Phipps. In a current extension of this work, they have found that a single injection of 6 mg of ENU per mouse induces a mutation rate 75,000 times greater than that considered to be a maximum permissible level of risk from a whole year of exposure to radiation. In short, ENU is a super mutagen. Says Bill, "Fortunately, ENU is apparently not encountered outside the laboratory, but it demonstrates that the mammalian testis can no longer be regarded as resistant to all chemical mutagens. It is disturbing to consider the possibility that there may be other chemicals with similar mutagenic potency to which man is exposed."

Work continues at ORNL to get more data on ENU and to determine if related compounds, such as methylnitrosourea, are as mutagenic. There are many questions to be resolved. Why is ENU more mutagenic in younger mice? What is its mutagenicity in treated females? Are chemically induced mutations less damaging than radiation-induced ones? Does ENU cause skeletal damage in the offspring? Bill continues to work with other chemicals as well. For example, he plans to use the specific-locus method to test ethylene oxide, an industrially important compound that Generoso found to cause chromosome damage in mice and that Bob Cumming and George Sega, other members of Bill's group, found to cause another kind of damage in mouse germ cells.

Chemicals vs Radiation

After the fire at Bar Harbor in 1947, the Russells began distinguished careers in radiation genetics in the mouse system. They proved that sensitivity to radiation differs not only between mice and fruit flies but also between the male and female mouse. They developed almost all the currently available mammalian mutagenesis tests in their ORNL laboratory.

Then when nuclear power came under fire in the 1970s and new emphasis was given to developing nonnuclear energy sources, the Russells started new careers in understanding chemical mutagenesis in the mouse. It has not been easy.

"Chemicals are so complex," says Bill. "Because they may be metabolized to form other compounds, we're not sure that the chemical we are testing goes to the target as does radiation. Because metabolism in the mouse may not always be the same as that in humans, we're not as confident about extrapolating mouse results to humans as we have been with radiation data. In my declining years, this problem of chemical tests has opened up a whole new bag of tricks."

Even so, the Russells, an eminent husband-and-wife team, have apparently established themselves as leaders in chemical mutagenesis of mammals, as they were in radiation mutagenesis. ornl

take a number

BY V. R. R. UPPULURI

Coin-tossing Enigmas

Alan and Betty play the following coin-tossing game. A fair coin is tossed till the end of the game. The game ends when a sequence chosen by either A (Alan) or B (Betty) happens first; that is, A wins over B if the sequence chosen by A appears before that chosen by B.

Let A choose the sequence of finding two heads in succession, HH, and let B choose the outcome of tails and heads, TH. Though a priori it appears that these two events have the same probability, a little reflection shows that this is not so. As a matter of fact, the probability of B winning this game is ¾. For all possible choices of sequence, the probability of B winning the game is given in the table below.

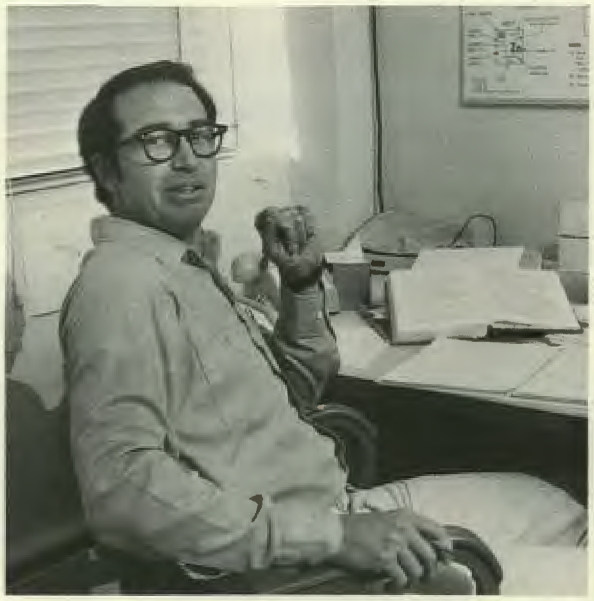
One may also ask for the average number of tosses necessary for a desired outcome. By the symmetry of the problem, the outcomes HH and TT will have the same answer of six tosses. It is interesting to note that the average number of tosses necessary to observe TH is four, which is also the average number of tosses required for the outcome HT.

This problem becomes very interesting if the outcome chosen by A is HHH and the outcome chosen by B is THH. Further details may be found in Martin Gardner's column in the October 1974 issue of *Scientific American*, on pp. 122–24.

The probability of Betty winning

Betty's choice \ Alan's choice	HH	HT	TH	TT
HH		½	¼	½
HT	½		½	¾
TH	¾	½		½
TT	½	¼	½	

Bill Butler received his doctorate in solid-state physics from the University of California at San Diego. After teaching physics at Auburn for three years, he joined the Metals and Ceramics Division at ORNL in 1972. His interest in superconductivity theory has dominated his work at the Laboratory ever since.



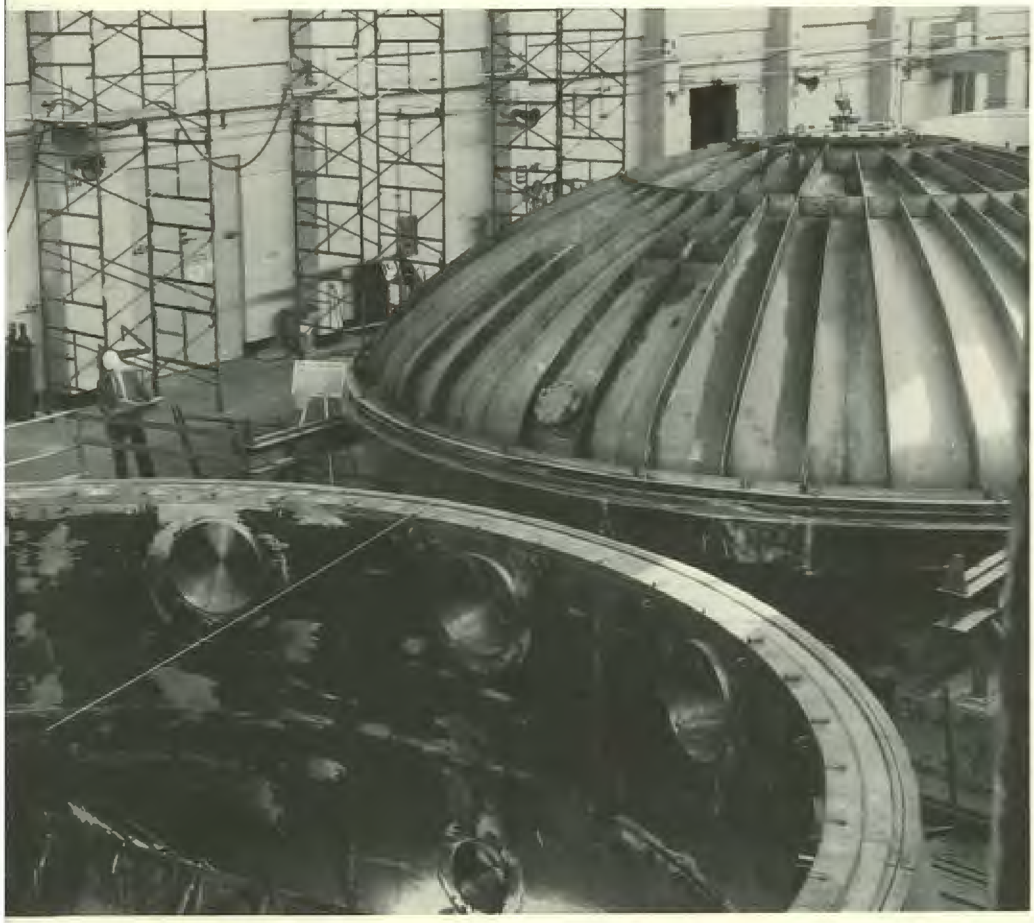
The Search for Higher Temperature

By W. H. BUTLER

The world's oil and gas wells may run dry in the next century, but an economic nightmare could be averted if today's dreams of new technologies come true. It is envisioned that we may someday obtain electricity from thermonuclear fusion reactors, from efficient magnetohydrodynamic conversion of coal, and from remotely sited power parks. We may speed from city to city at 133 m/s (300 mph) on magnetically levitated trains. And we may have automobiles powered by electrical energy stored in intense magnetic fields. But whether these concepts will be realized depends to a large extent on the magnitude of future advances in the technology of superconductors.

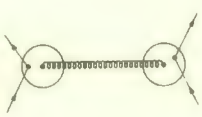
A superconductor is a metal which has no electrical resistivity at all. A current circulating through a loop of superconducting wire will continue to circulate indefinitely using no source of external power if the wire is kept in the superconducting state—one of the few examples of perpetual motion that can be realized on earth.

There is only one drawback to superconductors. They must be kept cold, very cold by ordinary standards. There is a temperature at which some metals abruptly lose their resistance to the flow of



The Large Coil Test Facility, under construction in Building 9204-1 for the Fusion Energy Division, will test superconducting magnets. Later generations of these magnets may benefit by progress in the development of higher-temperature superconductors.

Superconductivity

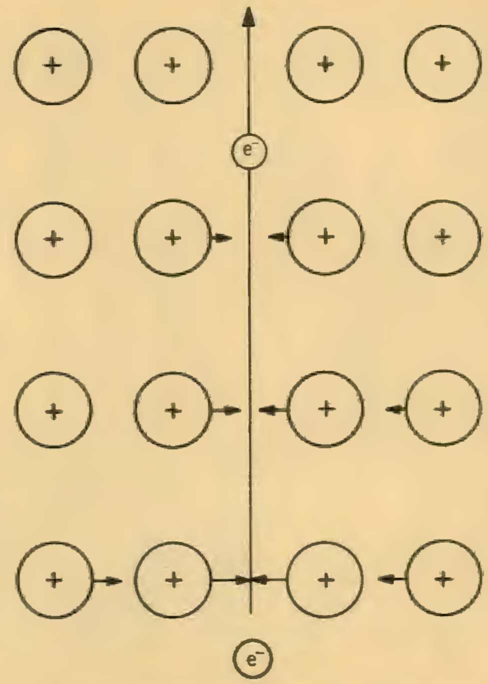


electricity. This critical temperature, T_c, varies from 0 for nonsuperconductors, such as copper, to about 23 K for a hard-to-make compound of niobium and germanium (Nb_3Ge). The Kelvin temperature scale, used to measure T_c, is similar to the centigrade scale except that it starts at absolute zero, which is -273°C; Nb_3Ge, for example, superconducts only if it is cooled below -250°C.

Applications

Despite the problems of refrigeration, superconductors are being used more and more. Their primary use is in electromagnets. Dozens of superconducting magnets are used in research at ORNL. They are usually the cheapest way of obtaining high magnetic fields over large volumes of material. For example, Gene Hise, in the Engineering Technology Division, is using a superconducting magnet to remove ash and sulfur from coal.

For some applications, superconducting magnets are essential. Fusion reactors which use intense magnetic fields to contain the incredibly hot plasma in which the fusion reaction takes place will not be economical unless the magnetic fields are produced by superconductors. Ordinary magnets would consume more



Superconductivity is caused by an indirect attractive interaction between the electrons in a metal. In this figure, the swiftly moving electron at the top is attracting the positively charged ions toward it. The more slowly moving ions, however, close in long after the electron has left the scene. A second electron may be attracted to the wake of positive charge left by the first electron.

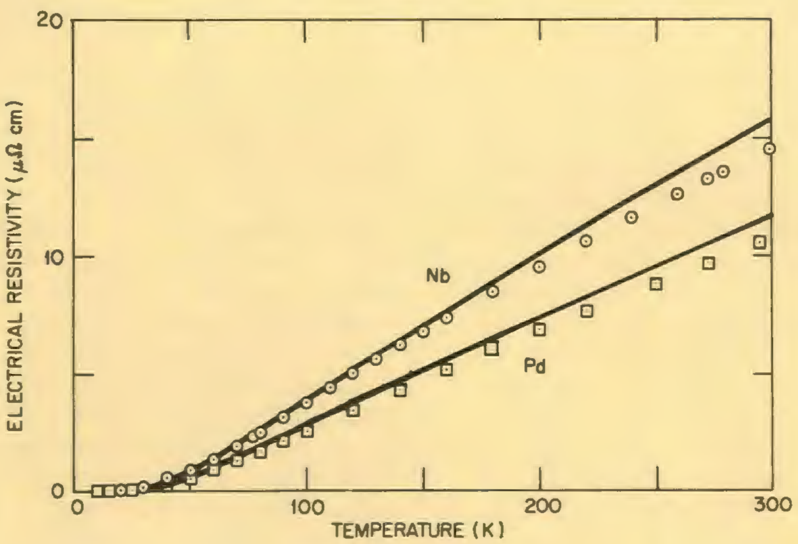
power than the machines could produce. ORNL is the lead laboratory for DOE's Large Coil Program. This $60 million program is designed to explore the engineering problems associated with building and operating the huge superconducting magnets that will be used in a prototype fusion reactor.

Other applications of superconductors appear to be on the brink of economic viability. In a process known as magnetohydrodynamics, coal can be directly converted into electricity by sending the hot combustion gases through an intense magnetic field. For economical operation, this field must be generated by a superconducting magnet. The transport of electrical power from one part of the country to another is now limited by transmission line losses because part of the transmitted power is dissipated as heat, but these losses could be eliminated if the transmission lines were superconductors. Furthermore, superconducting transmission lines would make it possible to site nuclear power plants far from populous areas. Land transportation systems have been designed that can transport passengers at 133 m/s by floating the vehicle on a magnetic field generated by superconducting magnets on board. Prototype superconducting motors and power plant generators are being built by Westinghouse and General Electric. All of these projects are technically feasible. Their realization is delayed primarily by the uncertainty of their economics.

Needed Improvements

The prospects for widespread use of superconductors would be dramatically improved if we could find a practical superconductor with a high T_c. A room-temperature superconductor may be an impossible dream, but an 80 or even a 30 K superconductor would have an enormous economic impact since it would free us from the necessity of using liquid helium as a coolant and would substantially reduce refrigeration costs. There are other important parameters of a superconductor besides T_c; these include the maximum magnetic field that the superconductor can withstand and the amount of current that it can carry. Research aimed at improving these parameters has been conducted at ORNL in separate groups led by Carl Koch in the Metals and Ceramics Division and Stan Sekula in the Solid State Division. Fortunately, these parameters are usually improved if T_c is increased.

Superconductivity is caused by an attractive interaction between any two electrons in a metal. Usually, we consider the interaction between two electrons to be repulsive because of their like charges. In addition to this direct, repulsive coulomb interaction, however, there is a weak, indirect attractive interaction called the *electron-phonon-electron* interaction. This attractive



The electrical resistivity of normal metals is caused by the same interaction between the electrons and the lattice vibrations that causes superconductivity. In this graph, the solid curves are resistivities calculated from first principles without adjustable parameters for the transition metals niobium and palladium. The circles and squares are the corresponding experimental values.

interaction can overcome the coulomb interaction in a rather subtle way, and if this happens there will be a temperature, T_c, below which some electrons form into pairs that condense into a new state of matter, the superconductor. Above this temperature, superconductivity is prevented by the thermal fluctuations which break up the pairs.

The electron-phonon-electron interaction can be understood by means of a simple analogy. Imagine two bodies lying on a soft mattress. The mattress will sag under the weight of one of the bodies, creating a depression into which the other body may roll. The bodies are attracted to each other, in this case, because of the sagging of the mattress.

A metal consists of negatively charged electrons that move rapidly through an ordered array of positively charged ions. The ordered array, or lattice, of ions plays the role of the mattress. Because of its negative charge, an electron will attract the nearby positive ions so that they sag toward it, creating a local region of extra-positive charges. Other electrons will be attracted to this region because of the pileup of positive charges, and an indirect attractive interaction will occur between the electrons. This is called the electron-*phonon*-electron interaction because it requires movement of the ions, and, according to quantum theory, this movement is composed of discrete units of vibrational energy called phonons.

One way in which the electron-phonon-electron interaction differs from the body-mattress-body interaction is in the time scale for the motions. Electrons are extremely light and move rapidly in a metal (about 10^5 m/s). The ions, however, being heavier, move more slowly, about 10^3 m/s. By the time the ions can sag toward the first electron and create the accumulation of positive charges which attracts the second electron, the first electron has moved far away. Thus, the attractive electron-phonon-electron interaction occurs between electrons that are far enough apart so that the repulsive coulomb interaction is not very strong.

John Bardeen, Leon N. Cooper, and J. Robert Schrieffer showed in 1957 that all of the remarkable properties of superconductors occur if there is a net attractive interaction between electrons. For this work, they received the Nobel Prize in physics in 1972. Theorists have postulated a number of mechanisms other than the electron-phonon-electron interaction that might cause an attraction between electrons, but there is no convincing evidence that these mechanisms are effective in real materials. Our best hope for a room-temperature superconductor may indeed come from one of these exotic mechanisms, but right now they seem to be a long shot.

When superconductivity is caused by the electron-phonon-electron interaction (as it apparently is in all known

"There has long been a good-natured rivalry between theorists and experimentalists interested in superconductivity."

instances), the most important parameter in determining T_c is the mass enhancement, λ. The mass enhancement is a convenient dimensionless measure of the strength of the interaction between the electrons and phonons (lattice vibrations) in a metal. It gets its name from the fact that the conducting electrons in a normal metal are slowed down by the same interaction that leads to superconductivity. They behave, in fact, as if their mass has been increased by a factor of $1 + \lambda$.

The mass enhancement parameter varies from about 0.1 for some metals which have only one conduction electron per atom to about 2.0 for high-T_c superconductors such as Nb_3Ge and Nb_3Sn. In order to find higher T_c superconductors, it is important to understand the wide variations in λ. It is possible to express λ in terms of three quantities which can be related to our simple model of the electron-phonon-electron interaction:

$$\lambda = \frac{N(E_F)\langle I^2\rangle}{S} .$$

These three quantities are $N(E_F)$, the Fermi energy density of electronic states; $\langle I^2\rangle$, the average of the square of the electron-phonon matrix element; and S, the effective lattice stiffness.

The Fermi energy is an important concept in the theory of metals. Even at a temperature of absolute zero, the electrons in a metal are not all in the lowest energy state because only two electrons can occupy any state simultaneously, according to a law of nature called the Pauli exclusion principle. Consequently, the electrons fill up the lowest energy states available within the two electrons per state restriction. The highest energy of a filled state is called the Fermi energy. It is those states near the Fermi energy which determine the conductivity and superconductivity of metals. The number of states per unit of energy at the Fermi energy $N(E_F)$ is extremely important to the theory of superconductivity because it determines how many electrons will feel the electron-phonon-electron interaction. The higher the $N(E_F)$, the better the prospects for a high λ and a high T_c. Nowadays, for most metals $N(E_F)$ can be calculated fairly reliably from first principles (i.e., using only the crystal structure and the atomic number).

The lattice stiffness, S, is important in determining the strength of the electron-phonon-electron interaction because if the lattice is very stiff, the ions will not sag very much toward a passing electron, and the electron-phonon-electron interaction will be weak. It is still very difficult to calculate S from first principles, although John Cooke in the Solid State Division has achieved impressive results for niobium. Fortunately, lattice stiffness has been extensively studied experimentally using neutron diffraction, especially by Harold Smith and Nobu Wakabayashi, also in the Solid State Division.

The remaining factor in the formula for λ is $\langle I^2\rangle$. It is a measure of how much the energy of an electron is changed per unit of displacement of the surrounding ions. Several years ago, Balazs Györffy, a frequent visitor to ORNL from Bristol University, suggested to me that a certain assumption which has come to be known as the rigid-muffin-tin approximation might allow $\langle I^2\rangle$ to be calculated for a class of metals called transition metals. The transition metals are the 24 elements which form groups III B through VIII B of the periodic table. They have a complicated electronic structure because a dense set of energy levels derived from the *d* states of the isolated atoms lies near the Fermi energy. This dense set of energy levels makes these metals and their compounds good candidates for high T_c superconductivity because $N(E_F)$ is usually high. It so happens that λ and T_c vary in a complicated way as one proceeds through a transition metal series. Sometimes they follow $N(E_F)$, sometimes not. The reason for this variation has been a subject of discussion and controversy for years.

By extending the electronic structure computer codes developed in the Metals and Ceramics Division over the past decade and by using Györffy's rigid-muffin-tin hypothesis, Sam Faulkner, Jeffrey Olson, and I were able to calculate $N(E_F)$ and $\langle I^2\rangle$ for the transition metal niobium. I later extended the calculation to all of the transition metals of the 4-*d* series. The result was a quite good agreement between theory and

"I believe that materials with much higher T_c's can be made, and that by diligent study of nature's subtleties we shall learn how to make them."

experiment, and, most importantly, an understanding of the variation in T_c throughout the transition metal series. I found that $\langle I^2 \rangle$ depends strongly on the nature of the electronic states at the Fermi energy. If these states participate strongly in the interatomic bonding, $\langle I^2 \rangle$ will be high. Some metals have a high Fermi energy density of states but a low $\langle I^2 \rangle$ and T_c because these states are concentrated near the atom and do not participate in the interatomic bonding.

There has long been a good-natured rivalry between theorists and experimentalists interested in superconductivity. The experimentalists' side has been expressed rather caustically by Bernd T. Matthias of the University of California at San Diego, who once pointed out that theorists can often do rather well at "*post*-dicting." That is, they can explain the results of experiments already performed, whereas they usually do poorly at *pre*dicting the results of experiments—especially the T_c's of new materials. (Regrettably for the superconductivity community, Dr. Matthias passed away in October of this year.)

In 1972, Philip B. Allen of the State University of New York at Stony Brook showed theoretically that a lattice vibration (phonon) can decay by exciting an electron which is in an energy state just below the Fermi energy into a state just above the Fermi energy, and that the decay rate is a detailed measure of how much attraction between electrons is contributed by each particular lattice vibration. In 1977, I was able to calculate this decay rate as a function of the wavelength and polarization of the lattice vibrations for the metal niobium. The calculation showed a high decay rate for certain wavelengths and polarizations. This result was soon confirmed in a beautiful experiment performed by Smith and Wakabayashi, who measured the decay rate using a neutron diffraction technique. This may have been the first successful *pre*diction concerning the electron-phonon-electron interaction in a transition metal.

At this stage, the rigid-muffin-tin approximation appeared to be working rather well, so Philip B. Allen, Frank J. Pinski at SUNY Stony Brook, and I proposed a more stringent test. We decided to calculate the electrical and thermal resistivities of transition metals in the normal (nonsuperconducting) state. Ironically, the same interaction between electrons and phonons which causes superconductivity is responsible for resistivity in the normal state. Good superconductors are typically poor conductors and vice versa. Resistivity calculations are numerically tedious, but they are a somewhat less ambiguous test of a theory of the electron-phonon interaction than T_c calculations because T_c also depends on the residual coulomb repulsion between the electrons. The results of these calculations were quite gratifying because they were in very good agreement with experimental measurements by Robert Williams and Peyton Moore of the Metals and Ceramics Division.

Unfortunately, all of this theoretical success has yet to produce a new superconductor. One reason for this is that nature is rather subtle. Many of the characteristics which tend to make a material a good superconductor, such as a high Fermi energy density of states and a low lattice stiffness, also tend to make it unstable. A prediction of a high T_c cannot be confirmed if the material cannot be made. On the other hand, if a suspected high-T_c compound exists, its T_c can be measured more easily than it can be calculated. My guess is that the next class of high-T_c superconductors will be discovered by a close cooperation between theory and experiment in which theory provides guidance and educated guesses about what types of compounds are likely candidates for a high T_c. Before theory can play its role in this discovery, however, a better understanding of the stability of metallic phases may be necessary.

Personally, I am optimistic about the future of superconductivity. I believe that materials with significantly higher T_c's can be made and that by diligent study of nature's subtleties we shall learn how to make them. The calculations of λ and T_c performed at ORNL show that we now understand the factors that control these parameters. Although it is not certain that practical, stable superconductors with much higher T_c's can be made, the potential benefits are so enormous that a substantial research effort is justified.

BOOKS

Breakthroughs: Astonishing Advances in Your Lifetime in Medicine, Science, and Technology *by Charles Panati. Houghton Mifflin Company, Boston, 1980. 306 pages, $12.95. Reviewed by W. S. Lyon, Analytical Chemistry Division.*

Prognosticating the future is an ancient and honorable pastime within the province of poet and peasant alike. Nostradamus, sixteenth-century astrologer and physician, couched his prophecies in vagueness, mystery, and confusion. Scholars studying these ancient writs have thus found it difficult to decide exactly what is to happen when. Modern-day forecasters, emboldened by armies of models, economic indices, and technical projections, are more specific: if the sky is to fall they can tell us its rate of descent, where it will land, and how much indemnity the local inhabitants will demand from the federal government. Allen Toffler in *The Third Wave* envisions the future of the United States as a cottage information industry; the Club of Rome says things will be bad (but not as bad as they were going to be five years ago); and Herbert W. Armstrong, founder of the Worldwide Church of God, editor of *The Plain Truth*, and author of many tracts and books including *The United States and Britain in Prophecy*, foresees a decline of the West and the millenium close at hand. (In preparation for these events Mr. Armstrong is rumored to be contemplating the removal of church headquarters from Pasadena, California, to somewhere in Jordan.) Such are three rather different views of the world of tomorrow. Somewhere in between these forecasts is the world of *Breakthroughs*.

Breakthroughs swam into my ken concurrently with *Science and Technology: A Five Year Outlook*, which was produced by the National Academy of Sciences. *Breakthroughs* has one author, Charles Panati; *Science and Technology*'s acknowledged contributors fill three pages. In format *Breakthroughs* looks and reads like those squib pages in *Reader's Digest*; the NAS volume has slick paper and reads like *American Scientist-Scientific American*. Both, however, present a rather optimistic view of the future. Panati, though obviously not equivalent to three pages of NAS members, is no Music Man who has left his "cree-dentials" at the hotel: the dust jacket describes him as a former head physicist at RCA, a former science editor of *Newsweek*, and the author of two other books and editor of a third. His antipasto seems to have been concocted in the following manner: he has clipped every conjecture, every oddball statement, every unique finding or controversial opinion he could find in press, scientific literature, or magazine, folded in some health items from *Prevention* and other natural food and vitamin publications, added a few items from *Psychology Today* and its compatriots, flavored the mixture with some *Science Digest* notes, and finally garnished it with an excellent imagination and lively writing style.

The result is a book of many short items, some paralleling those in the NAS volume, some few even better, but the greatest number completely passed over by the NAS. This backhanded compliment is, however, returned. For example, the chapter on the health of the American people in the NAS volume has more than three pages on smoking. Panati never mentions it. Panati is very big on eating, however. In part I, "Medicine," he has the subtitles "Eating to Grow Smart," "Eating to Sleep," "Eating for Better Mental Health," "Eating for Better Physical Health," and "Eat and Grow Thin." Under part II, "Science," one finds such topics as "Aging as a Curable Disease," "Babies after Sixty," and "Thinking Clearly at 120." This sampling of titles gives an idea of the audience (and its problems) Panati is addressing. I suspect the current culture of narcissism is responsible for Panati's heavy emphasis on personal concerns such as eating, behavior, pain, pleasure, sleep, health, and disease. But hard science is not ignored: both Panati and the NAS discuss quasars, neutrinos, the origin of the universe, and related topics. *Breakthroughs* includes a number of less "accepted" viewpoints such as the Maryland experiments on gravity waves, antimatter, and the possibility that the earth's core is made of methane. (Have we gone from a flat earth to a flatulent one?)

Technology makes up part III. Here computers, satellites, and hardware run wild. All the accepted energy panaceas are present (solar and fusion energies and windpower, for example). In addition one learns of hot rock power, levitating trains, car sonar, space agriculture, and space homes. The final item is "Listening for Aliens in the 1980's and 1990's." I think I hear some now.

This review is probably leaving the reader with the impression that *Breakthroughs* is shallow, frivolous, and useless. As a member of the scientific establishment, ORNL and its duly constituted representative should probably take this position. Much of the highly speculative material in *Breakthroughs* is probably junk. But controversy and oddball ideas are essential lubricants for scientific progress. As more than one learned philosopher of science has observed, new theories are not quickly and easily accepted; rather, proponents of the old theories die off. I hope to live long enough to see many of Panati's breakthroughs occur. And I cannot close this review without remarking that if Panati had been included among the authors of the NAS report, the list of contributors could probably have been reduced to a half page—and the report made considerably more trenchant and appealing to the mass of citizens who paid for it. ornl

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The following books in print have members of the ORNL staff as primary authors:

Fourth Book of Hydraulic and Ecological Features: Water Resource Regions of the Coterminous United States, by R. M. Cushman, S. B. Gough, M. S. Moran, and R. B. Craig. Ann Arbor Science, Ann Arbor (1980).

Photoelectron and Auger Spectroscopy, by Thomas A. Carlson. Plenum Press, New York and London (1975).

Survey of Energy Resources 1974, by H. E. Goeller, R. S. Carlsmith, W. L. Carter, E. L. Nelson, J. A. Patterson, and R. M. Perhac. Werner & McGregor, Washington, D.C. (1974).

Location and Well Being: An Introduction to Economic Geography, by Thomas J. Wilbanks. Harper & Row, New York (1980).

Plasma Scattering of Electromagnetic Radiation, by John Sheffield. Academic Press, New York (1975) and Atomidzak, USSR (1978).

Fur bearing Traffic Hazards

By BARBARA LYON

The tour-group member stood in the rank forest undergrowth on a path in Walker Branch Watershed and looked about her with eyes large with wonder.

"Have you noticed," she whispered, "we haven't seen a single sign of life since we got here?"

The popular misconception that any work with nuclear science kills the environment for miles around dies hard, and her preconceived convictions were strong enough to negate her surroundings of hardwood-pine forest, tangled growth underfoot, and rustling greenery throughout.

In point of fact, the Oak Ridge Reservation is dismayingly hospitable to wildlife. Jay Story of the Environmental Sciences Division is the recipient of all the wild animal sightings hereabouts, and in addition to the commonly seen groundhogs, skunks, possums, and raccoons, he has had innumerable reports of such unusual species as foxes, both red and gray; black bears, five sightings; a cougar, enough reports to convince him that there is a high probability of its presence on the reservation; two reports of coyotes, and he expects more; and many packs of feral dogs. The most exotic sighting was of a chimpanzee.

However, it is the deer, in a protected habitat and with no natural predators, that show the most alarming proliferation. If the estimate made by Dwight Flynn, a graduate student with the division in 1975, of about 250 animals is correct, the population today,

Jay Story, shown here with a heavily sedated bobcat trapped on the Oak Ridge reservation, is the Laboratory's wild animal expert now after six years of studying and trapping the large animals in the federally controlled areas around Oak Ridge. He has worked with mammals most of the time since he came to the Laboratory in 1963, when he first studied small animals, both in the wild and caged, in experiments relevant to radiation exposures. Although his major was in earth sciences, a minor in zoology and a boyhood on a farm have stood him in good stead for the years of experience leading to his current activities. For the past nine years he has been joined in his wild animal work by Tom Kitchings, environmental research park coordinator in the terrestrial ecology section. Most of the photographs accompanying this article were taken by Story, whose hobby in that field has led to contributions to the book *Mammals of the Great Smoky Mountains National Park* as well as the countless animal shots that have appeared in ORNL publications. Story is also a licensed pilot, and for about three years he used this training to perform otherwise impossible support studies, not only for the Environmental Sciences Division, but also for the Laboratory's environmental coordinator's office, and area security forces. He sees the small plane as a highly useful and economic tool in the management of the reservation.

or, Will you catch a deer in your headlights this year?

based on the yearly increase in sightings and automobile kills, can be extrapolated to over 2000 head.

In 1979, 73 deer were killed by vehicles in Oak Ridge, a sharp increase over the previous year's count of 45. The implication in these figures of escalation of the white-tailed deer population on this protected acreage is alarming to Story and his colleague Tom Kitchings, who have been studying the matter for three years.

According to the Environmental Sciences Division records, 126 deer were killed or reported hit by vehicles on Oak Ridge roads from the fall of 1969 through 1977. In 1979, twice as many bucks were killed as does. The peak months were October, November, and December, the normal breeding season. There were kills on White Wing Road, on Scarboro Road near the Y-12 hill, on South Illinois near the University of Tennessee Arboretum, and even in the city proper of Oak Ridge, but by far the most deer were killed on Bethel Valley Road, Bear Creek Road, and the Oak Ridge Turnpike west toward the Oak Ridge Gaseous Diffusion Plant. Peak hours of the day for deer mortality corresponded, not surprisingly, to the peak traffic hours of 6:00 to 8:00 AM, but the second highest number of kills occurred between 10:00 PM and 12:00 midnight, corresponding to peak deer activity. Last year, six deer were killed in the east end of town, where the human population is fairly dense.

Under normal living conditions, the white-tailed doe produces one fawn per year. A high incidence of twinning indicates good habitat and abundant food, as does the extension of the breeding season into the spring. In 1978, Kitchings and Story reported observing multiple offspring twice as often as single fawns as well as finding fawns that still had spots as late as October. There was evidence that does were bearing offspring within a year of their birth.

One gauge of population growth is nightlighting. Driving around the reservation at night with a hand-held 200,000-candlepower aircraft landing light, the census taker sweeps the surrounding vegetation with light until the characteristic glow of twin jewels appears, denoting the presence of an animal. The vehicle is then stopped and the creatures highlighted for sex identification and age estimation.

Kitchings and Story have nightlighted the reservation for a deer count at regular intervals for the past four years. Although the number of kilometers covered has been reduced to save fuel, the number of deer seen per kilometer has increased dramatically, from 11 in 1976 to 40 in 1979.

The impact of machine on deer can be traumatic for more than the animal. At 7:30 one evening last December, a group of Oak Ridgers witnessed a deer kill on Bethel Valley Road, east of Solway Bridge. Driving west from Melton Hill Drive, they saw a westbound car in front of them lose its lights, swerve violently into the left lane, and come to a stop. Thinking the driver had suffered a seizure of some kind, the following driver passed him, made a U-turn, and shone his headlights on the stalled car to avoid collision from eastbound traffic. It was now evident that both headlights and the grille of the stalled vehicle had been smashed, and the driver had gotten out of his car and was looking dazed and shaken. The deer had appeared in his lights without warning; the driver was probably traveling 80 km/h (50 mph), a moderate speed, but too fast to avoid the impact. Although the animal had not been killed outright, having gotten up and run into the woods, it was undoubtedly a kill. Story calls every struck deer a kill, as the deer's bone structure is too fragile to withstand any blow from a moving vehicle.

The driver's chief concern, in his bemused condition, was that he would be fined for killing a deer illegally. And, indeed, this is true in some states. The story is told of a man in Maine whose car was charged by a moose one dark night and totally demolished. He had seen the animal soon enough to stop and give it time to get away. Instead, it took offense at the headlights and came at the poor man's Chevrolet with antlers atilt. The moose died as a result, and the hapless driver was fined $500 by the state of Maine for killing a protected species.

This, however, is not the case in Tennessee. The accidental killing of a protected animal, so long as the prescribed procedure is followed, is not deemed illegal. Correct procedure entails notifying the

authorities of the incident and leaving the animal to be picked up by them. A fine is, to be sure, imposed for "illegal possession of an animal," and that goes for any part thereof.

In the reporting of struck animals, Story has the 24-hour cooperation of the Oak Ridge Police and Fire departments as well as that of the shift supervisors for the three Union Carbide Corporation installations in Oak Ridge. He carries a monitor with him at all times through which they can reach him. No matter what time of day or night, as soon as he learns that a deer has been hit, he goes to the spot without delay. Of the 45 deer recorded killed in 1978, 10 had been removed from the scene before Story's arrival, and 9 had not been killed immediately and had moved back into the woods. Most of the animals that do this are found later, dead or dying, at varying distances from the accident location.

Story takes the carcass to his laboratory for certain routine examination procedures. Weight and external measurements are recorded, and tissue samples are taken from the major organs for pathological information. The age of each animal is determined from the number of teeth present and their wear. The reproductive tract of each female is examined for information about pregnancies. Samples of muscle, liver, and thyroid go to Health Physics for radionuclide information. Each animal is examined for external and internal parasites; the brain lining is examined for the presence of meningeal worms; the body cavity is checked for "body worms" sometimes found free in the body cavity; and the abomasum, or fourth stomach, is collected along with its contents in order to determine the number of stomach worms present. The abomasal parasite count has been found useful in determining whether or not a deer range is overpopulated, because the number of these worms increases with increasing deer density. So far, these counts in reservation deer do not indicate overcrowding. The balance of the carcass is destroyed or used to bait traps in support of Story's carnivore study on the reservation.

On the whole, the deer on the Oak Ridge site appear to be in good physical condition, as shown by the pathological examinations. An exception occurred in 1977 when eight blind fawns were found and euthanized; a pathologist examined the eyes from five of these animals and found malformations of the ocular structures similar to those reported by veterinarians in other parts of the United States. There was no apparent cause for this unusual outbreak of eye malformations, and the fawns exhibited no other abnormalities.

By baiting box traps with loose salt, graduate student Flynn trapped seven deer in 1974–1975 and equipped them with ear tags and numbered collars. Since then, Story and his colleagues have tagged 21 more, including four that were given radio transmitters having a range of about 2 km. Using a tracking receiver with a directional antenna, the ecologists

are able to triangulate the positions of the deer. On the basis of specific locations taken over the two-month period from mid-October through mid-December of 1978, Story and Kitchings discerned a pattern that they feel may be representative of the adult animals of the herd. Two does remained within territories of about 100 ha each as determined by over 130 locations, whereas a buck's territory encompassed over 700 ha. The inference is that breeding season broadens the male deer's range, accounting for the increase in deer kills in the late fall and for the preponderance of bucks killed.

The tagged deer continued to be monitored, and in 1979 the two does under study more than doubled their range, an increase that Story attributes to the extensive timber-harvesting and -clearing operations performed in the past year on the reservation, much of it in battle with the pine beetle.

There are very few nontraumatic methods of population control in such situations. Relocation is one, and the Tennessee Wildlife Resources Agency has managed to trap for relocation a total of 53 deer, admittedly a drop in the bucket, but relocation of large animals is not a simple job. Moreover, the problem is not confined to this area but is widespread across the country, even where annual harvesting is permitted. The Oak Ridge reservation is not amenable to hunting for several reasons, most of which involve security regulations and the proximity of human activities. Hunting is permitted on the Savannah River reservation, which has about eight times the acreage of the Oak Ridge reservation and fewer buildings. Story and his colleagues are disturbed by the evidence of poaching, an illegal activity that is difficult to control, and dogs are known to have killed some deer. But on the whole, the deer as adults have no natural predators in Oak Ridge, unless you count the automobiles.

Very young fawns could fall prey to the bobcat, which, although not populous, still is well represented in the area. Story and Kitchings have trapped and radio-collared nine cats, tracing their movements by means of radiotelemetry. It is their belief that there are probably no more than a dozen bobcats on the reservation.

In order to instigate a herd management plan, the researchers felt a need to establish the deer's preference in habitat. This they have done by the method of trail counting. Deer are year-round trail makers, leaving well-defined paths

The problem is nationwide. For the last several years the known highway kill of deer has exceeded the sportsman's bag. How do you avoid hitting a deer? Here are methods used by a veteran game protector.

1. November is the month of peak danger. Deer are pursued in the fall and bucks are in the rut. At these times deer are less sensitive to road danger. Dawn and dusk and foggy, rainy weather are the times when more deer are hit simply because they are most active then. A driving tip is to take it easy in deer country in the fall as twilight falls or by dawn's early light. Watch it when it drizzles. (During early 1974, in the period following the oil shortage of late 1973, when the 55-mph speed limit was inaugurated, the upward trend of deer-vehicle accidents reversed itself in Michigan.)
2. Be alert when you see DEER CROSSING signs. Game departments place them on the basis of deer actually killed along that stretch.
3. If you see one deer, be ready for more. Usually several will travel together. And they have little sense of vehicular danger. A deer standing by the side of the road may suddenly leap right out in front of you. If one runs across the road, expect others to bound along after it.
4. If you catch a deer in your headlights while driving at night, pull off the road, come to a stop, turn off your lights, and blow your horn. Because the animals appear to be hypnotized or blinded by the lights, they are not frightened away by the lights alone.

as they go over the same routes repeatedly in their feeding habits. Kitchings' and Story's count of over 100 trails crossing 17 1-km transects reveals that trail abundance was greatest in areas of mixed pine and hardwoods, but scrub pine and cedar areas were heavily used as well. As the transects approached upland hardwood dominance, the trails became scarcer. Also little used were areas with steep slope.

The ecologists' conclusion is that clearing blocks of hardwood near major highways and planting pine trees in their stead could be one reason for the deer's moving to areas where they are in greater danger from automobiles. The maintenance of strips of highway right-of-way near power and gas lines also creates browsing fields that bring the deer closer to their peril.

Meanwhile, the sightings increase as the peripatetic deer become less and less elusive. Clyde Mayes, who drives a shuttle bus between ORNL and Y-12 nine times a day, has made a hobby of deer sightings over the years. As of early August, he had already spotted 62 this year, including three sets of twins. He expresses surprise that so many have been abroad in the heat of the summer, a time when a lull in sightings and kills usually occurs. In 1979, on the same shuttle run, he saw 27, and the year before that, 16. None, he says, were seen by the shuttle drivers before 1960, and in all the years since then, he has seen a total of 74 before this year. It is therefore highly probable that his 1980 count will exceed all previous sightings. He has never hit a deer, but Story has while working on the reservation at night, proving that even a reasonable awareness of the likelihood of such an accident is no insurance against it. However, total disregard could be fatal, particularly in high-speed, two-way traffic. So far, the damages from the auto-deer conflict have been measurable only in money.

Deer researchers in other parts of the United States have concluded that the most effective means of minimizing deer-vehicle collisions is to maintain a continuing program of informing the public of the hazard. Public awareness of the danger is more likely to reduce the number of collisions and the seriousness of damage than are efforts to reroute the travels of deer or to fence the animals off from highways. ornl

Herb Krause uses this molecular beam-laser apparatus to study elementary carbon reactions.

information meeting highlights

Chemistry, August 5

Nuclear Magnetic Resonance Gives Inside Look at Coal in the Solid State

ORNL organic chemists have developed a nondestructive analytical technique that has the highest resolution yet attained for distinguishing important structural characteristics in the carbon skeleton of coal and the manner in which these characteristics change during coal reactions.

The scientists are using nuclear magnetic resonance spectroscopy to study organic structure by employing the 1% naturally abundant ^{13}C nuclide as a structural probe. The ORNL chemists and some scientists elsewhere have extended the scope of high-resolution ^{13}C-NMR spectroscopy, previously limited to structural studies of molecules in solution, by adapting the technique to the study of matter in the solid state.

NMR is based on the principle that nuclei with an odd mass number (such as ^{13}C and hydrogen) will absorb electromagnetic radiation of a characteristic frequency when placed in an external magnetic field. The radiation causes nuclei in low-energy spin states to flip to high-energy spin states. When the nuclei "relax," they return to their low-energy spin states and emit radiation of the same energy absorbed. The resultant NMR signal indicates how many of a particular type of atom are present and which other atoms are bonded to the atom under study.

Ed Hagaman of ORNL's Chemistry Division has used solid state NMR to look at ^{13}C in bituminous coal. Using 100-mg powdery samples of Illinois no. 6 vitrinite spun at 250,000 rpm in a 2.35 T magnetic field, he has obtained information on the immediate bonding environments of carbon in coal. The chemical environment of a nucleus is indicated by slight (part-per-million) changes in frequency of absorbed radiation caused by differences in the electron density that surrounds nuclei in varied chemical environments.

Some of Hagaman's findings on Illinois no. 6 vitrinite are as follows:

- The coal's organic matter statistically consists of 70% aromatic carbon and 30% aliphatic carbon.
- All of the organic oxygen in this coal is bound to aromatic carbons. Ten out of every 100 aromatic carbons are bonded to oxygen. Seven of these oxygen atoms are phenolic (C–O–H), with the remainder being in ether linkages (C–O–C).

Also, the organic chemists at ORNL have looked at chemically treated coals. NMR gives them the capability of getting functional group analysis on whole, solid samples of the raw coal and its chemical derivatives without the necessity of, and high inherent uncertainty accompanying, dissolution of the sample prior to analysis. With the powerful, solid state NMR technique, these chemists are elucidating the principal chemical changes that take place during coal conversion.

Chemistry, August 5

Molecular Beam Study of a Carbon Atom Reaction

The first molecular beam study of a chemical reaction involving carbon atoms has been achieved by an atomic physicist in ORNL's Chemistry Division. The study is significant because it provides detailed information on chemical reactions and because producing a carbon beam is exceedingly difficult. Basic understanding in this area may be applicable in the fields of combustion, high-temperature chemistry, and astrophysics.

Herb Krause, of the atomic and molecular collision dynamics group, has successfully reacted a beam of atomic carbon with nitric oxide (NO) gas to produce a carbon-nitrogen radical (CN) and oxygen. From this experiment he has determined exactly how the energy of the reaction is redistributed among the reaction products.

Krause produced a carbon beam by using an intense electron beam to heat a graphite rod to a temperature of 3500 K. Because the carbon beam consisted of carbon atoms and C_2 and C_3 molecules, he had to separate the carbon reactants by time-of-flight techniques. Carbon atoms are lighter and travel faster than the C_2, and C_3 molecules in a pulsed carbon beam, so the atoms arrive first at the reaction cell.

In this experiment, the beam of carbon atoms collided with NO in the reaction cell kept at room temperature. As a result, each CN molecule formed was left vibrating and rotating.

To detect the CN reaction product, Krause used laser-induced fluorescence techniques. At the precise time that carbon atoms entered the cell and reacted, he fired photons at varying frequencies using a pulsed tunable dye laser. By tuning the laser to particular vibrational-rotational states of the CN molecules, he excited these molecules to a higher state. When the molecules relaxed and returned to the lower vibrational-rotational state, they gave up their energy in the form of photons. Each photon released and detected indicated the presence of one CN molecule in a particular vibrational-rotational state.

By counting the photons with a photomultiplier, Krause determined that most CN molecules are in low rotational states of the lowest vibrational states. He found that the energy in the reaction is redistributed among the reactant products in the forms of 5% rotational energy, 15% vibrational energy, and 80% kinetic energy.

Why were no CN molecules observed in high rotational states? Krause surmises that, when the reaction occurs, a transient molecule is formed consisting of carbon, nitrogen, and oxygen (C-N-O) which exists predominantly in a straight (collinear) rather than a bent configuration. When the oxygen breaks away in a collinear configuration, the CN recoils and is left vibrating vigorously and rotating slowly. If the C-N-O were bent, more energy would go into rotation, and there is a greater probability that carbon monoxide might be formed in some reactions because of the proximity of oxygen to carbon.

Says Krause, "Studies like this are important because they allow very detailed tests of basic chemical reaction theory—a more definitive test than would be possible if only a measured reaction rate constant were compared to that theoretically calculated."

Analytical Chemistry, July 21–22

Spark Source Mass Spectrometer Can Analyze Radioactive Samples

ORNL has developed a spark source mass spectrometry system that provides the Laboratory with a unique capability for studying highly radioactive materials. It can detect trace elements in radioactive solid samples in concentrations as low as 10 ppb.

This new analytical system is expected to be of use in evaluating the effectiveness of nuclear fuel reprocessing techniques and in determining whether radioactive wastes have been properly prepared for isolation. The ORNL spectrometer will be used to analyze undissolved residues in solutions of highly irradiated reactor fuel. The information obtained with this system could help chemical engineers determine whether they have produced insoluble wastes—the most suitable and safest for disposal.

ORNL's Analytical Chemistry Division has four spark source mass spectrometers, one of which has been extensively modified by R. J. Warmack and Joel Carter for analyses of samples that have high gamma-ray levels (100 R/h). Their redesign allows samples to be handled remotely under hot cell conditions so that electrodes made of or bearing the samples can be loaded directly into the mass spectrometer by master-slave manipulators.

Located at ORNL's High-Radiation-Level Analytical Laboratory (Building 2026), the charged source for the spectrometer is enclosed by lead shielding. The samples are loaded onto micromanipulators, and the electrodes are adjusted remotely with electric motors. A television camera at a remote-electronic-control panel is used to view the samples during sparking.

When a high-voltage discharge is passed between the electrodes, all elements in the samples at the electrodes' tips are ionized by the spark. The positively charged ions are guided through narrow slits to produce a thin beam. Ions in the collimated beam are first separated, according to their energies, in an electric field produced by curved, electrically charged plates. The beam then passes into a magnetic field for mass separation.

The two fields acting together cause all particles having a certain mass-to-charge ratio to converge at one point on a photographic plate. Particles having different ratios fall along other points on the plate. The position on the plate identifies the element, and the intensity of each point indicates the concentration of the particular element.

Spark source mass spectrometry has the advantage of permitting detection and measurement of elements and their isotopes without chemical treatment of the sample. Now, the new ORNL development in spark source mass spectrometry allows analysis of all solid materials, even the most radioactive.

Fusion Energy, May 12–13

Advances in Beta and Neutral Beam Heating in ISX-B

Like a balloon being blown up short of its bursting point, beta is still being pushed beyond a theoretically predicted critical value at ORNL's Impurity Study Experiment. Beta is the ratio of plasma pressure (the product of plasma temperature and density) to magnetic pressure exerted by the continuing field and a measure of the efficiency with which the magnetic field is used for containing the plasma. Theory predicts that at a certain beta, called critical beta, a tokamak plasma—the ionized gas in these doughnut-shaped fusion devices—exerts so much pressure against the magnetic field confining it that the plasma becomes unstable and vanishes as it loses its energy to the tokamak wall.

In ISX-B, the central value of beta has been raised this year from 8 to 11%, and the average beta value (root mean square) has been increased from 3% to more than 4% without evidence that a limit has been encountered. Similar betas have been achieved in Russian and Japanese tokamaks. Theorists have predicted that the average critical beta would be 2 to 2.5%. The search for beta limit in ISX-B goes on.

It is believed that commercial tokamak devices will require average betas in the range of 5 to 10% to produce power economically. The ISX-B attainment of an average beta of 4% means that an important economic parameter has been raised to within one-half of the level needed for the production of economical fusion power.

To increase beta in ISX-B, researchers have focused their efforts on raising the pressure of the plasma contained by the tokamak's 1.2 T magnetic field. That is done primarily by increasing plasma temperature and density using the neutral beam injection technique pioneered at ORNL.

Two neutral beam injectors developed for ISX by ORNL researchers have attained the highest neutral beam powers ever measured in a neutral beam injection system. The injectors produced neutral beam powers of 1.7 MW of hydrogen and 2 MW of deuterium, a hydrogen isotope. As a result, the ISX plasma containing hydrogen and deuterium was heated to 20 million degrees at a relatively high plasma density.

The increased neutral beam powers were made possible by increasing the current in the ion sources and by raising the voltage in the system. Last year, by using two 60-A sources with the potential of supplying 1.5 MW of neutral beam power to the plasma, researchers were able to heat the ISX plasma to 15 to 17 million degrees. This year ISX is equipped with two 100-A ion sources with the potential of providing 3 MW, or twice as much neutral beam power as the injectors delivered to ISX last year.

Each new injector can attain more than twice the power achieved by each ORNL injector used on the Princeton Large Torus, which reached record-high plasma temperatures exceeding 80 million degrees in 1978.

Four new injector systems, based on a cooperative design and experimental program between ORNL and Princeton's Plasma Physics Laboratory, were fabricated by private industry and are being installed on Princeton's new Poloidal Divertor Experiment, a tokamak designed to test the ability of special magnetic coils to remove impurities from the plasma. The PDX injectors are each 50-kV systems, whereas the ISX injectors each use 40 kV. The joint heating experiment, ORNL/PPPL, is expected to supply 6 MW into the PDX plasma, raising its temperature close to what is required for a power-generating fusion reactor.

ORNL continues to demonstrate the feasibility of pellet refueling for maintaining or increasing the density of the plasma. A gunlike pneumatic injector that operates on the principle of a miniature air rifle has successfully increased ISX plasma density fivefold by injecting tiny pellets of frozen hydrogen into the superhot plasma's center.

To enhance the heating of electrons in the plasma, ORNL researchers have installed a gyrotron on ISX. Developed by the Varian Corporation in collaboration with ORNL, this gyrotron provides microwave power resonant with the electron cyclotron motion. Studies done on ISX last year with another gyrotron developed by the Naval Research Laboratory have shown that electron heating increases linearly with such microwave power.

ORNL has also demonstrated that microwave heating can be used for the initial breakdown of hydrogen or deuterium gas into a plasma. Because microwaves require lower voltages than the plasma current typically used for breakdown, this finding is expected to be useful for improving the economics and simplifying the design of the Fusion Engineering Device, which will focus on solving engineering problems associated with fusion reactor development.

Ripple studies on ISX may aid in the simplification and improved economics of the FED design. As the number of magnetic coils is reduced on tokamaks, the resulting wavy toroidal field causes increased ripple

The engineers in the picture on p. 5 of the spring 1980 issue of the *Review* were erroneously identified. Standing with John Wolfe is Jim Crowley, the lead designer of the electric core in the Thermal-Hydraulic Test Facility.

in the plasma, thus threatening its confinement. Research is under way at ISX to determine how much ripple the plasma can stand. The answer will guide FED designers in deciding the minimum nmber of magnetic coils required to confine the plasma.

Studies are also being done on ISX to determine which coating on the "first wall" can best withstand bombardment from high-energy particles from the plasma. Of the coatings developed by Sandia National Laboratories under contract to ORNL, titanium carbide has been found to undergo the least melting.

Progress continues in using new diagnostic instruments for characterizing the ISX plasma. Laser-induced fluorescence systems developed elsewhere (Kernforschungsanlage, Jülich, and General Atomic Company) are being used to measure the plasma's impurity content, and far-infrared formic acid lasers developed by ORNL's Physics Division are used to measure plasma electron densities and current profiles on ISX-B.

ISX is a small machine, but its contribution to plasma physics and engineering design of fusion reactors belies its size. Perhaps its greatest claim to fame this year is that it holds the world's record for neutral-beam-power density.

Analytical Chemistry, July 21–22

Positron Spectroscopy

ORNL researchers have developed a positron gun that can be used to complement electron spectroscopy in analyzing surfaces for features such as structure and impurities. The ORNL positron gun design has been used by a group at Brandeis University to achieve the first measurement of low-energy positron diffraction from single-crystal copper.

A positron is the positively charged antiparticle of the electron. Positrons are emitted by radioactive isotopes such as ^{58}Co and ^{22}Na.

The principal developers of the positron gun are Les Hulett and John Dale of the Analytical Chemistry Division, with assistance from Subra Pendyala, a consultant from the State University of New York at Fredonia. In his doctoral thesis completed several years ago at the University of Western Ontario, Pendyala stated that positrons can be produced in a narrow energy range at 1000 counts/s. The gun developed at ORNL produces monoenergetic positrons of more than 100,000 counts/(s·cm^2).

Because of its 2.6-year half-life, ^{22}Na is the preferred source of positrons for the ORNL gun. Because sodium positrons are emitted in a wide energy range of 0.5 eV to 550 keV, the ORNL researchers sought a material to slow down the fast positrons. They found that specially prepared tungsten can moderate the fast positrons to thermal energies and reemit the positrons with low kinetic energies in the narrow energy range of 0 to 2 eV. ORNL researchers then reaccelerate the positrons to 50 to 2000 eV for the purposes of their research.

Hulett and his associates used single-crystal tungsten supplied by Mike Chang and Homer Harmon of ORNL's Solid State Division. To improve the counts per second of the beam of monoenergetic positrons, the ORNL researchers used high-temperature heat treatment on the tungsten to reduce bulk defects and to clean the surface by volatilizing oxide.

Because of its so-called negative work function, tungsten is effective at generating monoenergetic positrons following bombardment by radioactive sources. That is, the nuclei of tungsten repel the positrons more than its electrons attract them, so the positrons entering the solid are expelled in a narrow range of thermal energies.

Hulett and his colleagues have performed energy loss spectroscopy by bouncing a positron beam emerging from the tungsten moderator off a target surface such as silicon or another piece of tungsten. The amount of energy lost when the positrons strike the silicon surface is determined by measuring the final energy of the reflected positrons in a detector, or energy analyzer.

According to Hulett, spectra of positrons reflected from silicon and tungsten surfaces show the same discrete energy loss effects that are seen in spectra for ordinary electrons, although there are some subtle differences because positrons interact with matter in a different manner than do electrons. The ORNL researchers found that the positrons underwent an energy loss of 15 to 25 eV upon bombardment of the metal surface being analyzed. This energy loss information helps scientists understand the surface structure.

The discrete energy loss effect is due to plasmon excitation. As Hulett explains it, the target electrons are like bedsprings that vibrate in phase when bombarded by a sufficiently energetic projectile. When a baseball is thrown with velocity at bedsprings, it will transfer a discrete amount of energy to the bedsprings, which will vibrate in phase. Similarly, if positrons bombard a silicon surface with a large amount of energy, much of this energy will be transferred to the silicon electrons which vibrate in phase. This electron vibration is called plasmon excitation.

Hulett plans to use positron spectroscopy to expand on the Brandeis group's LEPD work and to analyze the composition of surfaces, to find impurities in surfaces, and to determine surface structure (which differs from the bulk structure of a material). He believes that the information gained from positron spectroscopy will complement that obtained with electron spectroscopy.

Fortunately, much of the same equipment used for electron spectroscopy can be used for positron spectroscopy, so the positron gun (whose development was funded by ORNL seed money) is a cost-effective source of analytical information.

Mel Halbert, designated mentor for the newly acquired Spin Spectrometer in the Holifield Heavy Ion Research Facility, received his doctorate at the University of Rochester in physics, reporting on "X Rays from Mesonic Atoms" in his thesis. He joined the Electronuclear Division (later merged with the Physics Division) in 1955, working on the 63-in. cyclotron with Alex Zucker until 1963. When it was built, he moved to the isochronous cyclotron (ORIC), and he is today involved in heavy-ion reaction mechanisms. Here Halbert describes the latest attachment to the new heavy-ion facility.

The Spin Spectrometer:

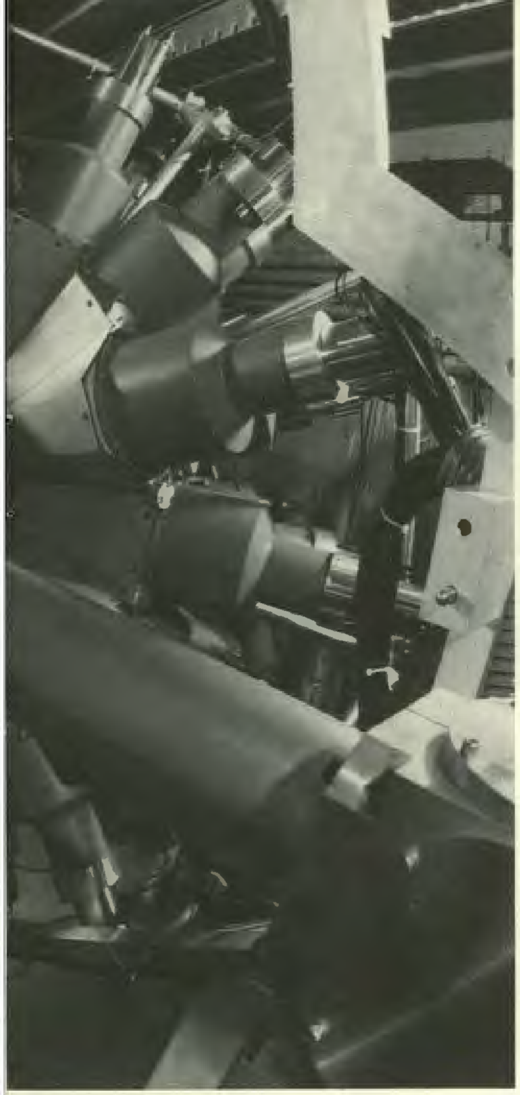
By M. L. HALBERT

On April 8, 1980, an impressive instrument of a new type was set up at the Holifield Heavy Ion Research Facility. Named the Spin Spectrometer, it consists of an array of 72 gamma-ray detectors completely surrounding a sample being bombarded by heavy ions from the Holifield accelerators. The aim is to catch and measure all the gammas given off by a highly excited nucleus as it settles down to its ground state.

The Spin Spectrometer is a handsome device. Visitors have likened it to a satellite for exploring outer space, but its purpose is the exploration of inner space, the innermost reaches of the atom. This instrument is the first of its type designed specifically for research in nuclear physics. It will offer a far more complete view of nuclei and nuclear reactions than has ever been available before.

Motivation

Why build such a complicated instrument? What do we expect to learn? Perhaps I can convey the basics without a full lecture on nuclear reactions. Consider a highly excited nucleus formed by the fusion of a projectile ion such as ^{16}O, ^{20}Ne, or ^{40}Ar (to name only a few available from the Oak Ridge Isochronous Cyclotron) with the nucleus of a rare-earth metallic target, perhaps samarium, gadolinium, or neodymium. The fused system is very hot: in our experiments its excitation energy is typically about 150 MeV (corresponding to an absolute



The Holifield Facility's Crystal Ball

temperature of roughly 2 trillion degrees, over 100,000 times hotter than the interior of the sun). This hot nucleus will probably be spinning very rapidly, possibly as rapidly as it can without disruption by the centrifugal force.

The nucleus can have only a fleeting existence in this condition. In most cases it cools down considerably by boiling off about ten neutrons in succession within an unimaginably short time— 10^{-17} s, give or take a factor of 10. The neutrons carry off most of the energy but not much of the spin. The residual nucleus now finds itself in the awkward situation of being too cold to boil off one more neutron, yet still possessing a much larger spin and more nonthermal energy tied up in rotation than that associated with the nucleus's normal ground state.

The nucleus solves its dilemma and completes its deexcitation by emitting a cascade of as many as 30 or 40 gamma rays which carry off the rest of the spin and the energy of rotation. In the rare-earth nuclei it is well established that most of the gamma rays carry off two units of spin apiece. Thus by simply counting the total number of gamma rays emitted in one event, we can determine with reasonable precision what the nuclear spin was before the gamma cascade started. This is the main job of the Spin Spectrometer and accounts for its name. For each nuclear collision it tells us how many detectors were triggered by gamma rays. At the same time, it records the energy of each gamma ray. The sum of these energies equals the excitation energy of the nucleus before the gamma cascade began. Thus the Spin Spectrometer determines in a fairly direct fashion two of the most important characteristics of the residual nucleus—its spin and its excitation energy.

This information will be extremely useful for scientists interested in properties of nuclei at very high spins. For example, the relation of spin to excitation energy, usually characterized by an effective moment of inertia, can now be measured better than before. As another example, isomeric states of very high spin can be found easily and their decays mapped out quickly. An isomeric state is one in which the very fast gamma cascade is interrupted at one nuclear state because some unusual structural aspect of the state inhibits its decay. This causes the state to decay with a measurable lifetime, and the rest of the cascade is delayed.

Data from the Spin Spectrometer will also be uniquely useful for studies aimed at clarifying nuclear reaction mechanisms. We want to characterize the initial compound-nuclear state, the ancestor of the one finally observed. We can do this by combining the data provided by the spectrometer with experimental and theoretical knowledge of the energy and angular momentum carried off by the particle emissions. If we accumulate similar data on a large number of such ancestor nuclei, we can map out the population of the various initial spin states for a particular reaction at a given bombarding energy. Such information is very important for testing theoretical models of nuclear reaction mechanisms.

How It Works

Each detector consists of a hermetically sealed aluminum can with 1-mm-thick walls containing a transparent prism of crystalline sodium iodide—much like a large crystal of rock salt—that is about 19 cm long and weighs about 6 kg. The NaI is very hygroscopic; the hermetic seal is essential to keep it dry. Activated with about 1% thallium according to a well-known recipe, the NaI is a scintillator. It emits a flash of blue light immediately after a gamma ray interacts with it, and the intensity of the flash is proportional to the energy deposited by the gamma ray. The scintillations are viewed through a glass window at the large end of each unit by means of a 12.7-cm-diameter photomultiplier tube. It converts the flash of light into an electrical pulse whose size is proportional to the amount of energy released by the gamma ray and whose time of arrival is precisely defined, within a few nanoseconds. Each pulse, along with its counterparts in the other detectors from the same cascade of nuclear gamma rays, is processed within a few microseconds by custom-built electronic circuitry installed nearby. The resulting digital information is transmitted to the Holifield facility's computer where samples are displayed on-line and where data are permanently recorded on magnetic tape.

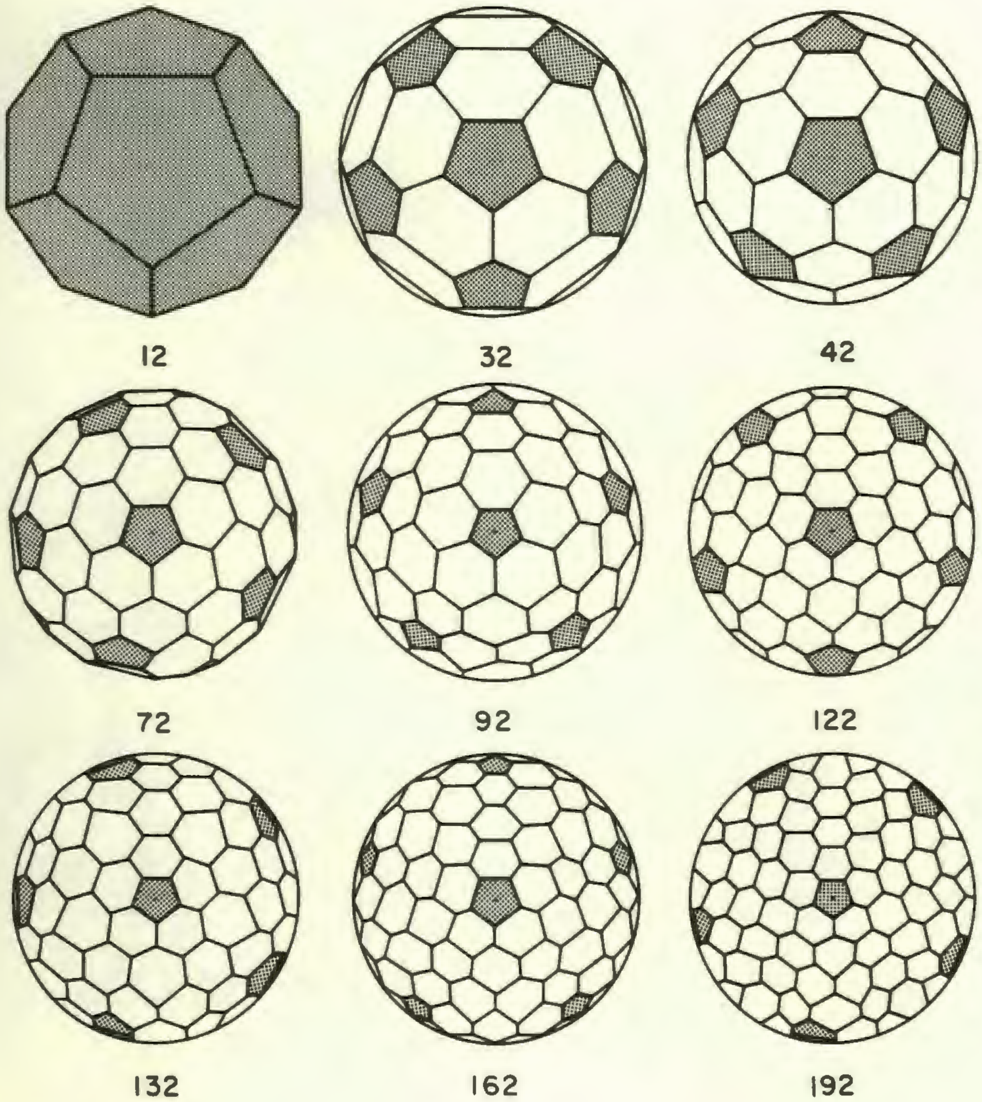
In the center of the Spin Spectrometer is a 33-cm-diameter spherical reaction chamber that occupies the inner cavity. The

People

Demetrios G. Sarantites, professor of chemistry at Washington University in St. Louis, has been the prime mover in the conception and realization of the instrument. Since 1976 he has been an active collaborator with members of the ORNL research staff, bringing apparatus, research associates, and students with him for our joint experiments with the Oak Ridge Isochronous Cyclotron. John Hood, engineer at the Washington University Cyclotron Laboratory, did most of the design work and supervised construction of the Spin Spectrometer in his shop. His accomplishment can best be appreciated by realizing that aside from the support mechanism, the instrument has no right angles at all!

A major role has been taken by David Hensley, ORNL nuclear physicist and computer specialist. He designed all the special electronic circuitry for the Spin Spectrometer, including the computer interface, and wrote the computer programs for data acquisition. His advanced concepts of hardware and software have made data collection with the Spin Spectrometer a practical reality.

I should also mention specifically the work of James Barker, a member of the Physics Department of St. Louis University, who designed the fittings for the spectrometer's spherical reaction chamber. He will be spending his sabbatical next year with us in the Physics Division, under an arrangement with Oak Ridge Associated Universities.—M.H.



The Spin Spectrometer is based on a 72-sided polyhedron, a member of this family of polyhedra with 12 pentagons each, the remaining faces being hexagonal. The first of these, the dodecahedron at the top left, is one of the five Platonic solids. The second in the family has 32 faces, including 20 hexagons, and provides the pattern on which soccer balls are made. One can go on surrounding the 12 pentagons with additional hexagons, giving the other polyhedra shown here.

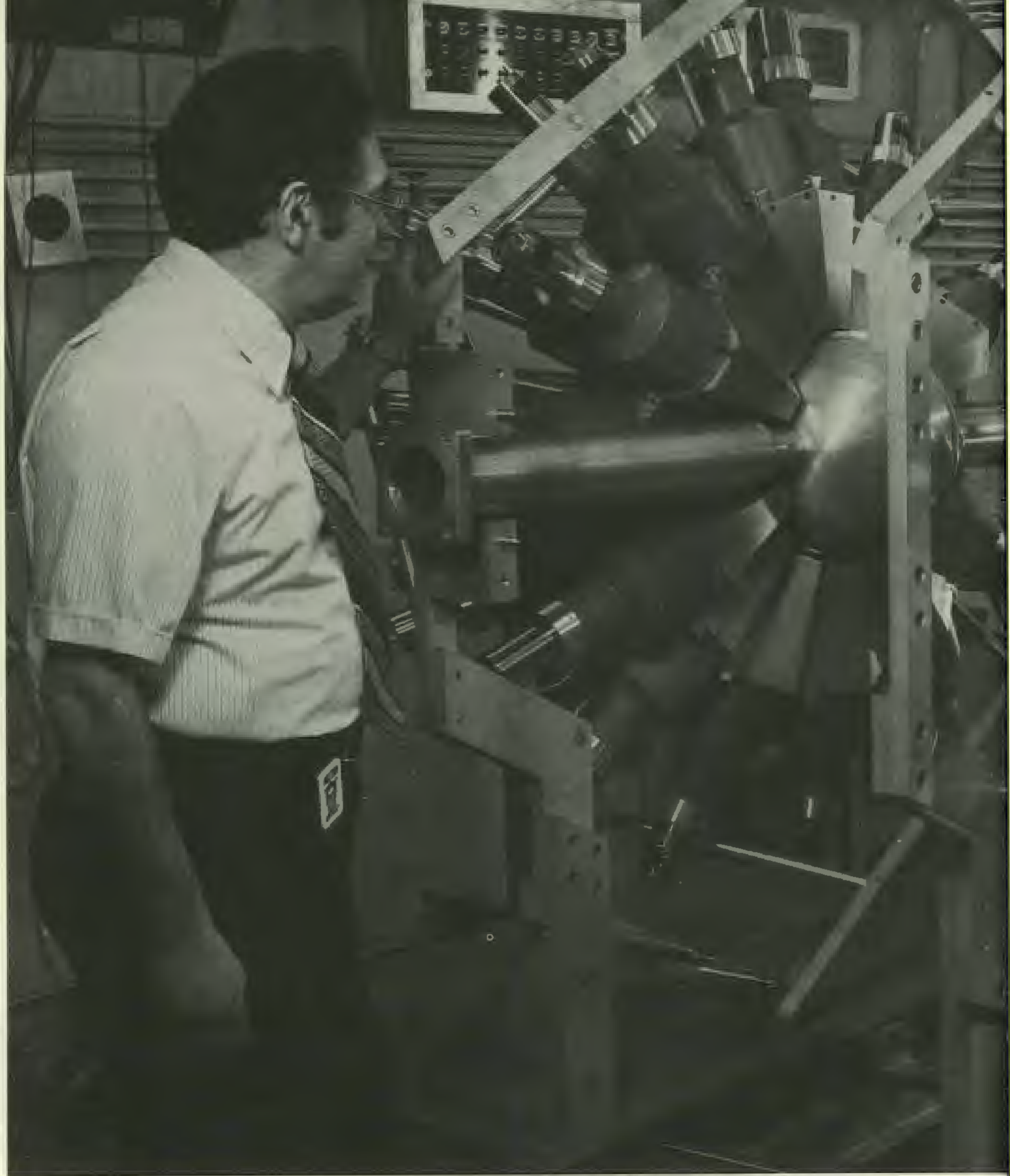
The basic geometry of the Spin Spectrometer. The dark polygons represent the 12 pentagonal detectors; the other 60 are identical irregular hexagons.

target to be studied is mounted on a rod that positions the target at the center of the sphere. Other mounting hardware is placed inside the sphere for experiments requiring particle detectors in addition to the gamma-ray detectors. The beam from either of the Holifield accelerators, or from the two operating in series, enters the sphere, passes through the target, and exits on the opposite side. To allow for the entrance and exit vacuum pipes, two detectors are omitted from the assembly, leaving 70. In some experiments, external detectors may be used as well, for example, to detect the neutrons or other particles emitted as the hot nucleus cools down. This would require temporary removal of additional units from the complete assembly. However, for discussion of the geometry I will continue to speak of the full complement of 72 detectors.

Geometry

The geometry of the Spin Spectrometer is based on a polyhedron bounded by 12 regular pentagons and 60 identical irregular hexagons (i.e., each pentagon is surrounded by 5 hexagons). The 12 basic groups of six detectors fit together perfectly, with no space left over. The two detectors removed for the entry and exit beam pipes are pentagonal.

This 72-sided polyhedron is one member of a family of polyhedra bounded by 12 pentagons and various numbers of hexagons. The first of these, actually having no hexagons, is the dodecahedron, one of the five Platonic solids. The supporting framework outlined by the rods outside the spectrometer traces out a dodecahedron. The



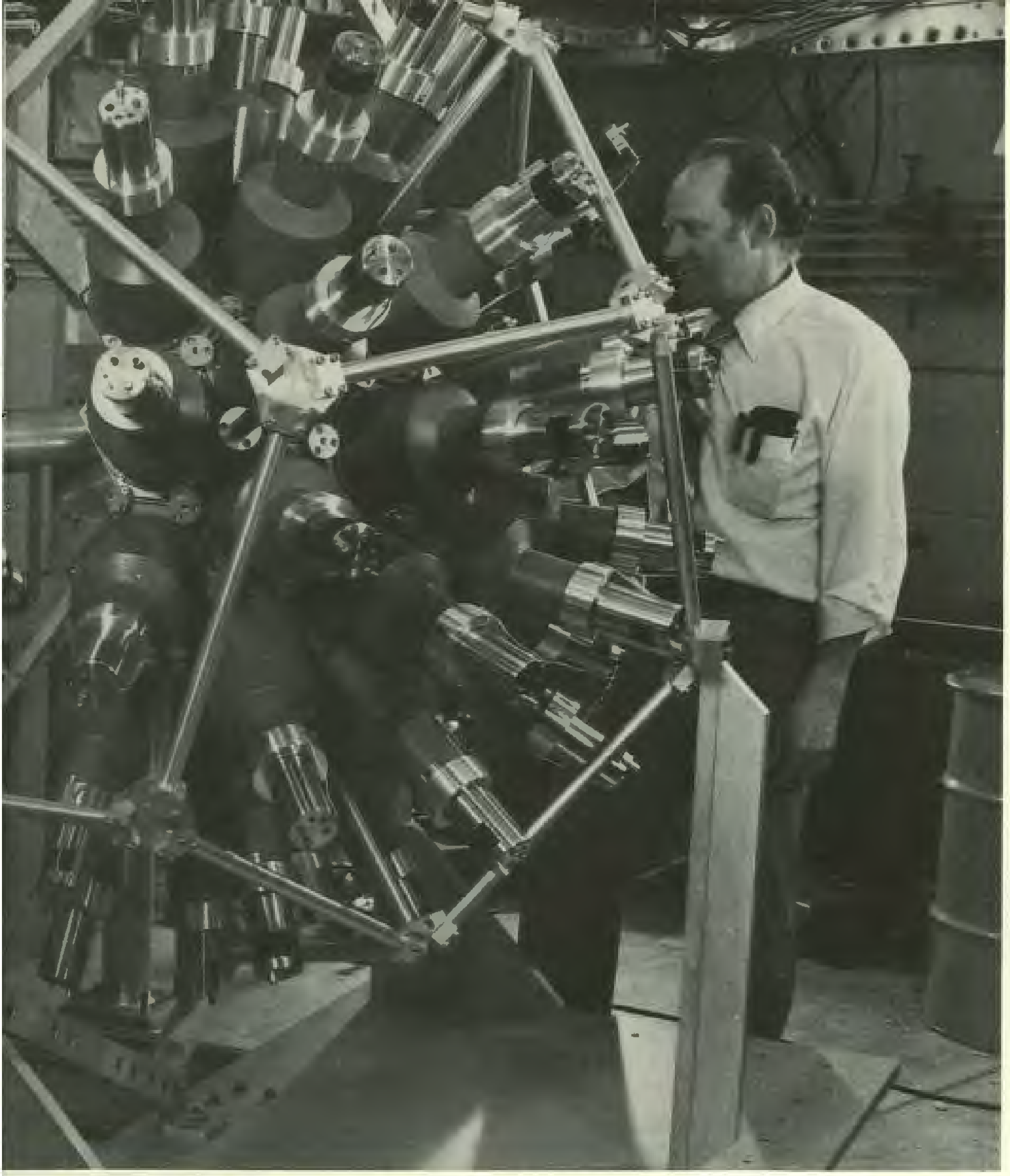
second polyhedron has 32 faces, 20 of them regular hexagons. Soccer enthusiasts will recognize it immediately as a truncated icosahedron, one of the 13 semiregular Archimedean polyhedra. By continuing to surround the 12 pentagons with additional hexagons, one obtains polyhedra with more and more faces, although the hexagons are no longer regular and generally are not identical.

The 72-sided polyhedron may be derived by cutting off 12 corners of a pentagonal hexecontahedron, a polyhedron bounded by 60 identical but irregular pentagons. The Spin Spectrometer may thus be called a truncated pentagonal hexecontahedron if a jazzier name is required.

The Archimedean solids have been known as theoretical constructs for well over 2000 years. The soccer ball is a recent reduction of theory to practice and perhaps the only one for the truncated icosahedron. I would guess that the Spin Spectrometer is the first realization of *its* abstract geometry. Whoever speaks of the rapidly decreasing time lag between theory and practice ought to be confronted with this 2000-year gap!

Of course, other types of polyhedra could have been used to surround the target completely, but all others are bounded partly by polygons with three and/or four sides. Detectors with these cross sections have sharper corners than pentagonal or hexagonal ones, and sharp corners increase the chance that secondary radiation might escape into a neighboring detector, necessitating larger corrections to the data. Also, the sharp edges of triangular detectors make them harder to manufacture and fit together. So the geometry based solely on pentagons and hexagons is optimal for this application.

The choice of the 72-faced polyhedron was dictated by balancing considerations of physics against costs. As I mentioned, one of the main purposes of the Spin Spectrometer is to determine the number of gamma rays in each cascade, the so-called gamma-ray multiplicity. The nucleus starts out with no more than 60 to 80 units of spin before the cascade (or else it would not have survived disruption by the centrifugal forces). Since most of the gamma rays carry away two units of spin each, we expect multiplicities of as much as 30 or 40, but not more. For an instrument with 32 or 42 detectors, there is a good chance that more than one of the gamma rays will interact in the same detector. Such a multiple interaction will appear to be just one gamma, and thus the total number of detectors recording pulses will not accurately reflect the actual multiplicity. However, the chance of such multiple events is tolerably small when an instrument has twice as many detectors as the maximum number of gammas expected. Increasing the number of detectors beyond this level does little to sharpen the multiplicity determination because other effects begin to place limits on its precision.



Sarantites, left, and J. T. Hood examine the newly installed Spin Spectrometer at the Holifield Heavy Ion Research Facility.

Other Instruments

Is ORNL's Spin Spectrometer the only detector of its kind in the world? A similar instrument known as the Crystal Ball is now under construction at the Max Planck Institute for Nuclear Physics in Heidelberg, West Germany. It is a cooperative project with G.S.I., Germany's national laboratory devoted to research with heavy ion beams. It will have 162 detectors rather than 72, like the Spin Spectrometer. Its designers expect to optimize their instrument for another class of experiments that selects only those events in which none of the detectors adjacent to a given one registers a pulse. The instrument is scheduled for completion at the end of 1980. Many other heavy-ion research laboratories throughout the world are now giving serious consideration to construction of similar instruments or to new detector concepts to accomplish similar purposes.

The first Crystal Ball was recently completed at the Stanford Linear Accelerator Center for research in high-energy physics. This instrument is based on the geometry of an icosahedron. Each of the 20 equilateral triangles is subdivided into 36 smaller triangles for a total of 720 triangular faces, of which 48 are removed to allow for entry and exit of the beam. The individual units, although optically isolated from their neighbors, are housed in two hemispherical cans. (In the true style of high-energy research, a 1977 paper on performance of a 54-unit prototype section listed 32 authors.)

Outlook

It is clear that ORNL's Spin Spectrometer will be a very heavily used instrument. Long before it was even brought to Oak Ridge, ORIC beam time was set aside for five major experiments with it. Two of these include outside users in addition to the Washington University group. Now that the spectrometer is fully commissioned, there seems to be little doubt that there will be a flood of potential users with a wide variety of new ideas for exciting experiments. Fortunately, the instrument can accumulate data rapidly because of its nearly 100% efficiency. Also, it lends itself to remote processing of experimental data: outside users can take their magnetic tapes home and scan them on their own computers. The wealth of data recorded on these tapes can be scanned in different ways, providing from one experiment several complementary views of the nuclear structure and reaction mechanisms.

But the main importance of the Spin Spectrometer will not be merely as a new tool to do better what we have already been doing. We expect it to open new vistas on nuclear physics, ultimately leading to an understanding of nuclei stressed to the limits of their stability. ornl

awards and appointments

Chuck Scott is this year's recipient of the E. O. Lawrence Award.

Three of the Nuclear Division's four IR-100 Awards this year were for accomplishments achieved at the Laboratory. The DEPA-TOPO process for recovering uranium from wet-process phosphoric acid was developed by **Fred Hurst** and **David Crouse**; the portable fluorescence spotter for optical monitoring of low-level surface contamination was developed by **Dan Schuresko** and his colleagues in the Chemical Technology, Instrumentation and Controls, and Plant and Equipment divisions; and the continuous ring particle blender for loading light water reactor fuel rods was developed by **M. G. Willey** and his colleagues in the Metals and Ceramics Division.

Newly appointed head of the office of Program Planning and Analysis is **Truman Anderson.**

Ron Bradley has been named a fellow of the American Ceramic Society.

At the Tennessee Professional Photographers Association's annual convention this summer, **Lewis McCrary** and **Ward Bandy** were rated Certified Professional Photographers, the first industrial photographers in Tennessee to be so rated. Bandy also received the Tennessee Service Award. Photographers from ORNL who had prints of their work accepted for the salon were **Terry Marlar,** three photos, of which two received Second Awards of Excellence; McCrary, six photos, of which four received Second Awards of Excellence; **Jim Richmond**, five photos, of which two received Second Awards of Excellence and one was accepted for the Court of Honor; and Bandy, six photos, of which three received Second Awards of Excellence, one received the First Award of Excellence, and one was accepted for the Court of Honor.

Helen Braunstein has received the Professional Associate Award in the Natural Systems Assessment for Development from the East-West Environment and Policy Institute of the federally funded East-West Center in Honolulu.

Troyce Jones has received the Health Physics Society's 1980 Elda E. Anderson Award, its highest honor.

Julian Preston will serve as managing editor of the recently established journal *Mutation Research Letters*.

Bob McClung was named a fellow of the American Society for Testing and Materials, which has also chosen him for its Award of Merit. McClung was also named an Outstanding Engineering Alumnus by the University of Tennessee College of Engineering this year.

Chuck Coutant is a member of a national research group, sponsored by DOE and the American Association for the Advancement of Science, studying world environmental and societal consequences of a CO_2-induced climate change.

John Auxier has received the Defense Nuclear Agency's Meritorious Public Service Medal, its highest honor, for his contributions to the agency as a radiation consultant.

The **Annual Cycle Energy System Demonstration House**, given an Outstanding Engineering Award last spring by the National Society of Professional Engineers, has been further honored by being named one of the "ten outstanding engineering achievements" in the NSPE 14th Annual Outstanding Engineering Achievements Program.

A. P. Malinauskas has been named to the editorial board of the journal *Separation Science and Technology*.

V. E. Kane has been elected secretary-treasurer of the North American branch of the International Classification Society, a multiple-disciplinary society of scientists interested in multivariate classification.

C. S. Williams has been named regional representative for the Association for Computing Machinery.

Lee Berry has been named manager of the newly formed Elmo Bumpy Torus R&D Program.

The paper "An ENDF/B-V 227-Group Cross-Section Library for Criticality Safety Studies," by **Eddy Ford, Mike Westfall, Betsy Diggs, Curt Webster,** and **John Knight,** was selected for the Best Paper Award at the American Nuclear Society's annual meeting this year.

C. E. Bush has been appointed chairman of the American Physical Society's Committee on Minorities in Physics.

Abe Hsie was given the Distinguished Alumni Service Award by Indiana University, from which he received both his M.A. and Ph.D. degrees.

Dave Bjornstad has been elected to the Executive Council of the Southern Regional Science Association.

John Cathcart has been elected a fellow of the American Society for Metals.

For the fifth consecutive year, **Oak Ridge National Laboratory** has received the National Safety Council's Award of Honor for its safety record.

Three posters designed by members of ORNL's staff for the exhibit competition at the International Metallographic Society meeting in Brighton, England, last summer won first place in their classes. In the Unique, Unusual, or Other Technique class, the winning poster was the work of **Peter Angelini, Dave Stinton, Jack Lackey, Tom Henson, Larry Shrader, Noble Rouse,** and **Charles DeVore** of the Metals and Ceramics Division and of **Leon Smith** of the Information Division. Winning in the Color Micrograph class was a poster designed by Stinton, Angelini, Lackey, Rouse, and Smith. Also, First in Class was won by the exhibit "Depth Profile of Swelling in Ion-Bombarded Ni," designed and executed by **Nick Packan, Ken Farrell,** and **John Houston.**

Jim Regan has won the Medal of the National Cancer Institute of Japan as well as the Medal of Tokai University in recognition of his research, both at ORNL and in Japan last summer, on repair mechanisms of DNA.

Harry Arnold joined the Engineering Division in 1964, after working for two years in private industry, with a degree in mechanical engineering from the University of Mississippi. After 12 years spent on the engineering of energy-related projects, he transferred to the environmental impact section of the Energy Division as manager of solar and geothermal environmental projects. While there, he directed the preparation of more than 25 environmental analyses of DOE projects throughout the United States. He noted the frequent recurrence of religious issues in the projects, which led to many discussions with both Native Americans and U.S. government officials. The result was the research and experiences he describes here. Currently, Arnold is leader of the waste heat utilization group in the division's conservation and conversion technology section.

Energy Development and the Religious Freedom Act

By HARRY ARNOLD

In north-central New Mexico, DOE representatives met with Pueblo religious leaders to determine the extent to which the Pueblos' traditional religion might be affected prior to construction of a proposed 50-MW geothermal power plant. In southern California, the Owens Valley Band of the Paiute-Shoshone Indians sought assurance from DOE that a geothermal well would not diminish the flow of sacred hot wells at Coso Hot Springs. In southern Texas, the location of a geopressure well was changed because of the presence of an Indian midden. Native Hawaiians have publicly objected to the potential desecration of their goddess Pele by the development of geothermal energy on the slopes of Kilauea.

ORNL has been involved in the assessment of impacts on Native American traditional religions for all of the above projects by virtue of its technical support to DOE in preparing environmental impact statements. All of the examples except one occurred prior to August of 1978 and were evaluated for religious significance according to normally accepted societal impact criteria. However, these projects were similar to many other federal actions that had the potential for infringing on traditional Indian religions and that led to passage of Public Law 95-341, the Indian Religious Freedom Act, on August 11, 1978. This law was first used to

This sacred mountain peak overlooks the site of a proposed federal project. American Indians protested that the presence of the project will visually intrude upon religious ceremonies conducted on the mountaintop.

challenge a DOE project when ORNL was preparing the EIS for the Baca Geothermal Demonstration Project. This gave ORNL an opportunity to apply the experience gained in previous Indian religious issues to the implementation of the new law.

This experience with DOE projects and some information on a project closer to home which ORNL did not evaluate, the Tennessee Valley Authority Tellico Dam project, provide some insight into the manner in which religious freedom has become a factor in developing energy resources.

The Indian Religious Freedom Act established a federal policy of noninterference with "access to sites, use, and possession of sacred objects, and the freedom to worship through ceremonials and traditional rites" for Native Americans. As federal policy, implementation was delegated to the President, who was to report to Congress a year later the methods by which federal agencies and projects would carry out the policy. It was on or about that date, August 11, 1979, that the Eastern Band of the Cherokee Nation filed suit against TVA's Tellico Dam project on the basis of infringement of First Amendment rights to religious freedom and violation of the Indian Religious Freedom Act.

In the course of its support to DOE in the preparation of EISs, the Laboratory has found its greatest involvement in Native American religious freedom issues in connection with geothermal projects because of mystical or religious significance attached to unusual manifestations of heat from the earth, such as hot springs, geysers, fumeroles, and volcanic mountain peaks. Some phenomena are indeed spectacular, such as the desert surrounding Coso Hot Springs, which literally steams when rain hits it during cool weather.

At the time PL 95-341 was passed, ORNL was preparing the EIS for the Baca Geothermal Demonstration Project in New Mexico, and the Pueblos had indicated that religious infringement under the Religious Freedom Act would be an issue even before the date the President was to report the implementation procedure to Congress. The Laboratory was thus at the forefront of PL 95-341 implementation.

Our experience prior to that time was invaluable. Other projects, specifically Coso Hot Springs, the

Hawaii Geothermal Project, and the Pleasant Bayou Geopressure well, had encountered the potential for these same issues. Although the circumstances surrounding them were different, the projects were similar in many respects and probably would have come under PL 95-341 had it been in effect earlier.

The Act

PL 95-341 sets federal policy. There are no regulations or special agencies set up to carry out the policy; rather, each federal entity, through the President, is required to report to Congress, stating how that agency would implement the new policy. The general guidance contained in PL 95-341 is in the form of a preamble: "whereas traditional American Indian ceremonies have been intruded upon, interfered with ..." There are ten of these "whereases," and they state the following general reasons for Congress to establish policy in this area.

- Religious practices are an integral part of Indian life, are irreplaceable, and form the basis for Indian identity.
- The lack of a clear and consistent federal policy has often abridged religious freedom for American Indians through lack of knowledge or inflexible enforcement of federal regulations.
- Laws designed for purposes such as conservation and preservation of natural species were never intended to relate to Indian religious practices.
- Freedom of religion is an inherent right under the First Amendment.

In consideration of the foregoing reasons, it was therefore resolved "that henceforth it shall be the policy of the United States to protect and preserve for American Indians their inherent right of freedom to believe, express, and exercise the traditional religions of the American Indian, Eskimo, Aleut, and Native Hawaiians, including but not limited to access to sites, use and possession of sacred objects, and the freedom to worship through ceremonials and traditional rites."

Geothermal steam or Pele? This geothermal well in Hawaii uses heat that traditional Native Hawaiian religions consider to be sacred. Compromise may be possible, however, since Pele has always given her heat for the good of her people.

DOE took a two-part approach to implementing the policy: one was to set up an Office of Indian Affairs responsible for determining the effect of DOE activities on Native American cultures, and the other was to prepare the procedures for conforming with the federal policy for the President's report to Congress. Conformance would be in four steps:

- determine if any DOE action has the potential of infringing on Native American religion;
- design the action in such a way as to avoid any interference, if possible, by consultation with religious leaders;
- relocate or otherwise modify the action to minimize the impact in a manner acceptable to the religious leaders; and
- terminate the action if unavoidable adverse impacts cannot be made acceptable unless the Secretary of Energy determines there is a compelling national need for the actions.

As one might expect, the hard part is to determine whether there is going to be a potential for religious infringement in time for it to affect project decisions. To accomplish this, DOE has elected to make determination of the applicability of the Indian Religious Freedom Act a part of the EIS process, which by law must be conducted at the earliest possible stages of a project and prior to any irreversible decisions or significant commitment of funding. By this method, some information on cultural and archaeological resources is collected and evaluated as a part of the technical, environmental, and financial decisions in selecting candidate projects.

Unfortunately, there is one loophole; the archaeological evaluation usually is not designed to contend with the possibility that archaeological sites (graves, middens, and ceremonial mounds) and artifacts (pottery, jewelry, and projectile points) of ancient origin may also be modern—but secret—religious sites still in active use by a particular group of Native Americans. Thus the decision that

This is a satellite false color image of the Valles Caldera north of Los Alamos. This dormant volcano is a potential source of geothermal energy and is being explored by DOE and industry. It also contains many sites and landmarks of potential religious significance to Pueblo Indians who live on surrounding lands.

the archaeological resources either are or are not significant may overlook the modern religious significance of these same resources and inadvertently allow their destruction before a religious issue is discovered. There have been numerous complaints by Native Americans that sacred articles have been "stolen" from religious sites and are now on display in museums. Nevertheless, except for the possibility of unintentional damage, there is a good chance that Native American religious issues can be identified in time to carry out the federal policy of noninterference.

There is, of course, a catch. "Federal action" involves only federal support, cost sharing, regulatory action, or loan guarantee. Should a private concern perform site excavations or other activities prior to federal support, there is no protection of Indian religions—except, of course, where Indians hold legal control over the sites in question. And the irony of it all is that, should the government pull out of a project because of a potential for religious infringement, the private concern could pursue the same project without federal support and without regard to the religious issues.

Native American Religions

Native Americans, especially those identified by PL 95-341, include American Indians, Native Hawaiians, Aleuts, and Eskimos. It is not possible or even necessary to describe the traditional religion of each of these peoples in detail here. Three things stand out in general, however: (1) religion is normally inseparable from the traditional way of life; that is, religious customs and other cultural practices are closely allied with natural settings and group survival; (2) the religions often embody the all-encompassing elements of "earth, air, fire, and water," with specific sites either held secret or not specific within the universal nature of the religion; and (3) often more than one vested interest group is within a tribe or band, resulting in different groups of religious leaders to deal with as well as inconsistent or

incompatible recommendations for the ways in which religious infringement may be mitigated. These three factors are significant in identifying and determining the disposition of potential impacts on Indian religions.

To many people familiar with western religions, religion is celebrated in a special building, with some of the precepts and teachings extending to the conduct of everyday life. To many Native Americans, however, religious observances are tied almost completely to the day-to-day activities necessary for normal living. Water may be sacred in an arid region where the Indians' economy is based on agriculture. Religious observances are often tied to the seasons, which in turn mark the change in the agricultural cycle or in the location or availability of animals for food. An animal (such as the buffalo) which provided a band with much of its food, shelter, and tools might be revered. Certain herbs, animals, and materials have attained religious significance through their medicinal uses. Religious infringement, therefore, could be as simple as prohibiting by law the collection of eagle feathers; restricting access to a national park which is the only habitat for a certain herb or animal; or depleting a resource, such as water, which is essential to the nourishment of an agricultural economy.

Restricted access implies prohibition of entry to an area or to a specific religious site. If there is no identifiable religious site, yet there is a claim of potential impact on religious practice, the usual methods of determining impacts must be applied very flexibly. For example, the Pueblos in northern New Mexico state that water is the thread that ties the separate elements of their religion (and their life) together. Water falls from the sky, fills the lakes and streams, soaks into the ground, and nourishes the plants that are the basis for their agricultural economy. Religious infringement in this case is damage to the headwaters or watershed, pollution of the streams, and competitive consumption of the already scarce surface water and groundwater.

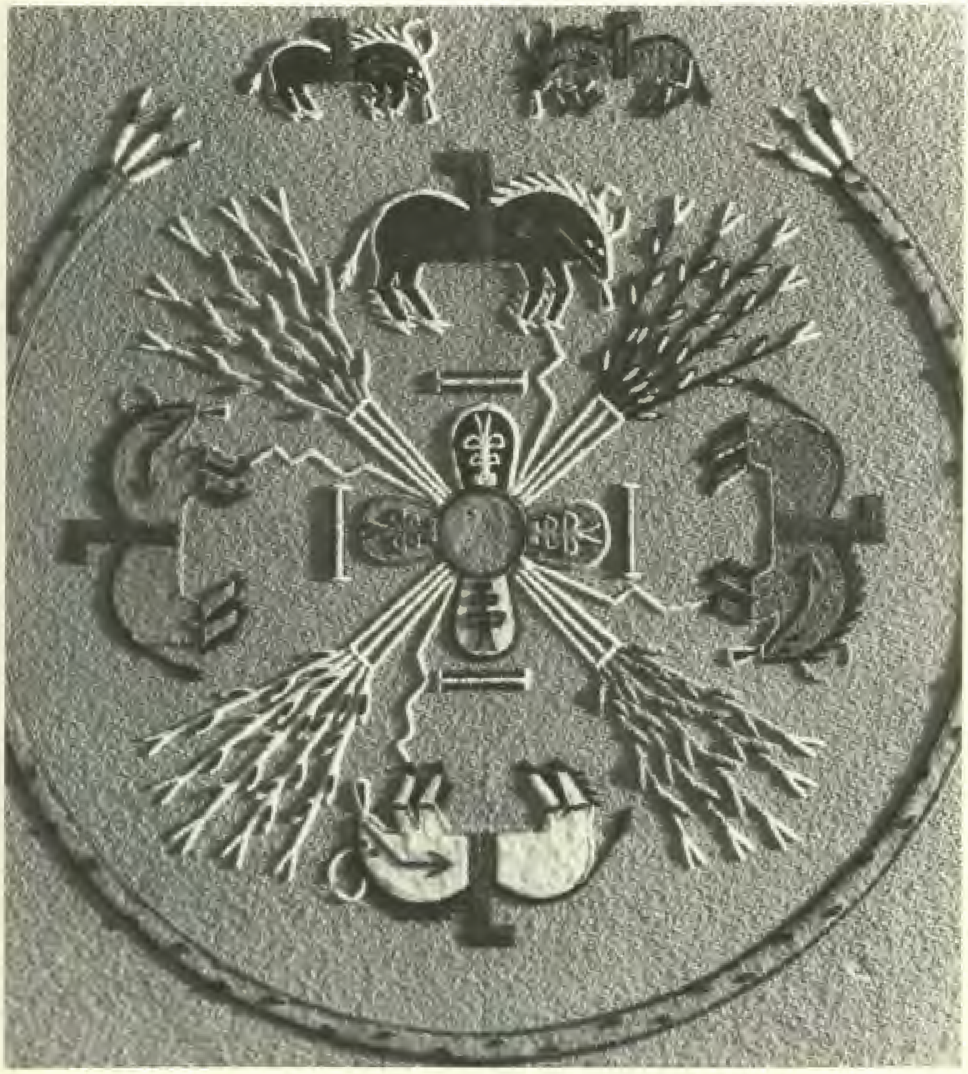
As another example, the Native Hawaiians hold Pele, the goddess of the volcano, to be central to their traditional religions. Contrary to the outsider's popular stereotype of Pele making the steam and lava,

Ulu—the breadfruit—is the gift of life according to Native Hawaiian tradition. In many Native American cultures a plant or animal important to group survival is given special significance in the religion of the tribe or band. In the Pueblo sand painting, the buffalo is depicted in its role as pollinator of the crops as it moves over the grain and brushes the tops with its belly, shown colored with pollen in the painting.

the Native Hawaiians contend that "the energy Pele explodes belongs to her and is her." More specifically, Pele does not make the heat; Pele is the heat. This is extremely important to any potential projects attempting to sink geothermal wells into the very heart of a volcano. Similar "site non-specific" religious sites are mountain peaks which spirits are believed to ascend after death to depart the earth, or river valleys filled with grave sites and burials which are central to religions based on the sacredness of ancestors and family lineage.

Thus, whether the religious sites are secret—and some are—or whether they encompass the total environment, they are often not readily identified even though they do exist.

A key element to the religious impact mitigation is the early identification of potential impacts. Later, the acceptable revision of a project becomes important. In either case, one must determine who speaks on behalf of the affected people. Religious leaders would be a logical choice to start with, but often they are not identified publicly. When they speak through a representative, the statement generally reflects a strictly traditional interpretation in which no interference is allowed, but which represents only one view of the project's impact on the band. The band's governing body, on the other hand, may seek some compensation, not necessarily monetary, in return for the presence of the federal project. There may even be a more liberal religious interpretation than that from the traditional religious leaders, as with some of the Native Hawaiians, who, rather than feel that any disturbance of Hawaii's geothermal energy is a sacrilege, believe it is only a sacrilege to use geothermal energy in a wasteful way that does not improve the quality of life for Native Hawaiians. Sometimes, added to these three competing interests within a band is a militant element, which threatens damage to the project; whether or not these threats stem from religious, material, or social interests varies widely.



Tellico

Tellico is not a DOE project, and ORNL was not involved in the religious issue there, but it is of local interest. Tellico is different for at least two reasons. First, the project was virtually completed prior to August 11, 1979, making the timing of any religion-based challenge seem questionable. Second, Congress exempted Tellico from "all other Federal law" when exempting it from the Endangered Species Act. Therefore, all of the appeals, which to date have been turned down, have been decided on the basis of First Amendment's grant of general religious freedom, rather than on the specific issue of PL 95-341, Indian religious freedom.

The Cherokee appeal was based on two religious issues. One is that the lake behind the dam would cover, and thereby restrict access to, the site of the ancestral village of Chota, once the capital of the Cherokee Nation and as such a religious site as well. The second issue was related to the burials excavated during the archaeological investigations associated with the project. Although treated by the project as an "archaeological resource," these burial sites, the Cherokees contended, are the graves of "aunts, uncles, and relatives with names," not just bones to be put "in cardboard boxes in the basement of McClung Museum."

Either of these infringements is covered specifically in the preamble of PL 95-341, but the applicability of the Indian Religious Freedom Act itself is in question for Tellico. Furthermore, if TVA has adopted the same approach that DOE adopted, the language Congress used in exempting the project from "all other Federal laws" might be interpreted as defining a "compelling national need." The Cherokees have allowed their appeal to lapse.

What Next?

The implications of the Indian Religious Freedom Act are far reaching. Not only is the question of defining religion open to negotiation, but the point at which another federal, state, or local law might take precedence (the Endangered Species Act, for instance) is also open to debate. Some lay persons have suggested that if a traditional religion embodied human sacrifice, PL 95-341 would permit it. Although this suggestion may seem extreme, it points out the latitude for interpretation that might be encountered. When combined with the extent of applicability as to who may challenge a federal action, PL 95-341 may become a significant factor in federal actions.

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One of Jay Story's wildlife photographs. For an account of his struggle with the growing number of deer-vehicle encounters, see article on page 24.