QUARTERLY REVIEW

SPRING 1991

MICHIGAN MEMORIAL PHOENIX PROJECT
THE UNIVERSITY OF MICHIGAN

NUCLEAR REACTOR LABORATORY
FORD NUCLEAR REACTOR
PHOENIX MEMORIAL LABORATORY

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The Nuclear Reactor Laboratory Quarterly Review is published and distributed to University of Michigan faculty and staff members to inform them of the unique research capabilities of the Nuclear Reactor Laboratory and to make them aware of the types of research in progress.

The Michigan Memorial Phoenix Project was founded on May 1, 1948, as a memorial to the 585 University of Michigan alumni, students, faculty, and staff members who died in World War II. The Project's charter is to explore ways and means by which atomic energy can be a beneficent influence in the life of man. Research support and services provided by the Nuclear Reactor Laboratory and a research grant program are the means by which the Project fulfills its charter.

NEW RESEARCH

NEUTRON ACTIVATION ANALYSIS

Biology

Peter Sandusky, a post-doctoral researcher working with Professor Charles Yocum, is performing basic research into the mechanisms of plant photosynthesis. The elements iron, manganese, and magnesium that are contained in plant chloroplasts are known to play a part. Instrumental neutron activation analysis is one of the techniques being used by Dr. Sandusky to determine concentrations of these elements in the chloroplasts.

Biophysics

Mr. James Drummond, a graduate student working under the direction of Dr. Rowena Mathews, is studying the synthesis of the protein, methionine. Mr. Drummond is using instrumental activation analysis to detect trace metal concentrations within the protein.

COBALT-60 IRRADIATOR

Biology

Assistant Professor Rolf A. Bodner is observing fruit fly mutations caused by low doses of gamma rays.

Mechanical Engineering

Constantine Kyriazis is observing gamma ray effects on the operational behavior of an ultrasonic sensor. The ultrasonic sensor is used in a radioactive environment as part of a robotics system. Mr. Kyriazis is using the cobalt-60 gamma source to simulate the radioactive environment.

Michigan Technological University-Chemistry

Dr. G. David Mendenhall, Professor of Chemistry at Michigan Technological University, and Stephen E. Amos of Himont U.S.A., Inc. are collaborating on a research project involving gamma irradiation of polypropylene in the cobalt-60 irradiator. The polypropylene is stabilized against radiation damage with various additives, and the effects of these additives at various doses are being estimated. They are observing the reduced chemiluminescence emission of the stabilized polymer after gamma irradiation. Light emission and reduction of physical properties are both caused by free radicals, so it should be possible to determine the equivalent radiation damage. The plastics being tested are used, or may be used, to make products such as medical supplies that are sterilized using gamma radiation.

FEATURE ARTICLE

LIFETIME EXTENSION OF NUCLEAR POWER PLANTS

As the population ages, so does the current fleet of nuclear power plants. But utilities believe that, as with people, there is still a lot of life in today's reactors after 40. Operating licenses for the oldest of the nation's 112 nuclear plants will expire beginning in the year 2000, but the utility industry and government authorities are laying the groundwork now to ensure that safe and reliable electricity generation can continue at these plants well beyond their original, 40-year terms.

The 40-year operating license term was defined somewhat arbitrarily in the 1954 Atomic Energy Act, which set the stage for the regulation and commercial use of nuclear power. Most federal licenses for hydroelectric plants were issued for 50-year terms, and 30 years was a commonly used utility amortization period for conventional fossil-fuel-fired generating plants. So, lawmakers decided that nuclear plant licenses would run for 40 years, but could also be renewed. In many other countries, nuclear power plants are issued open-ended licenses, with continued operation evaluated solely according to a plant's maintaining established levels of safety and economical performance.

The Electric Power Research Institute (EPRI) and the Department of Energy (DOE) are actively involved in research and development to support the nuclear license renewal option. They are jointly sponsoring a series of studies to address generic technical issues posed by potential age-related degradation in major systems, structures, and components important to extended operation under a renewed license and to identify options for managing aging.

EPRI and DOE are co-sponsoring lead plant demonstrations of the complete regulatory and technical program leading to a renewed operating license. These lead plant projects at Yankee Atomic Electric's Yankee Rowe pressurized water reactor (PWR) and Northern States Power's Monticello boiling water reactor (BWR) are expected to serve as pathfinders for other utilities weighing the license renewal option. The University of Michigan's 2 Mw research reactor will play an important role in this program.

A STRATEGIC OPTION FOR FUTURE ELECTRIC CAPACITY

The current crop of nuclear plants collectively represents some 100,000 megawatts, or about 15%, of the installed generating capacity in the country. Last year, the plants supplied about 20% of all the electricity generated. With occasional power shortages already occurring in parts of the East and many forecasters projecting a need for as much as 150,000-200,000 Mw of additional generating capacity later in this decade, utility interest in preserving existing nuclear plants is not surprising. Industry officials have said the cost to replace current installed nuclear capacity would range from $200 billion to $300 billion.

The Monticello pilot study suggested that for BWR's the most generically important deterioration mechanisms are corrosion-related phenomena within the primary pressure boundary. Figure 1 is a schematic of a BWR steam supply system, and Figure 2 is a detailed cutaway of a BWR pressure vessel. Such corrosion, including intergranular stress corrosion cracking in coolant piping has occurred at most reactors of that type and is already managed on a continuing basis through existing maintenance and water chemistry programs.

The pressurized water reactor study identified thermal and neutron embrittlement and fatigue as the primary degradation mechanisms for such key components as the reactor pressure vessel and support structures, the pressurizer, and the primary coolant piping. Figures 3-6 are typical PWR steam supply, pressure vessel, and containment configurations. An economic assessment methodology developed by the utility found that the bulk of the benefits of extending operation would stem from lower fuel costs and postponement of the capital cost of replacement, coal-fired capacity.

With the exception of the reactor pressure vessel, the containment building, and other major concrete structures, virtually every nuclear plant component has been replaced at one plant or another at least once, providing a base of experience and data for extended-operation maintenance planning. Early EPRI life extension studies concluded that even pressure vessel replacement was technically feasible, but the cost might be 10-15% of the cost of a new plant.

Figure 1
Boiling Water Reactor Steam Supply System

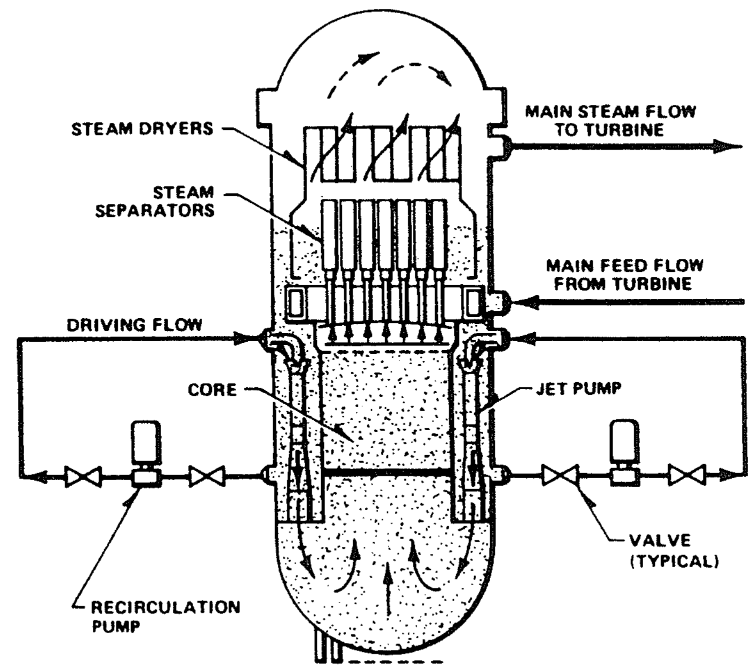


Figure 2
Boiling Water Reactor Pressure Vessel

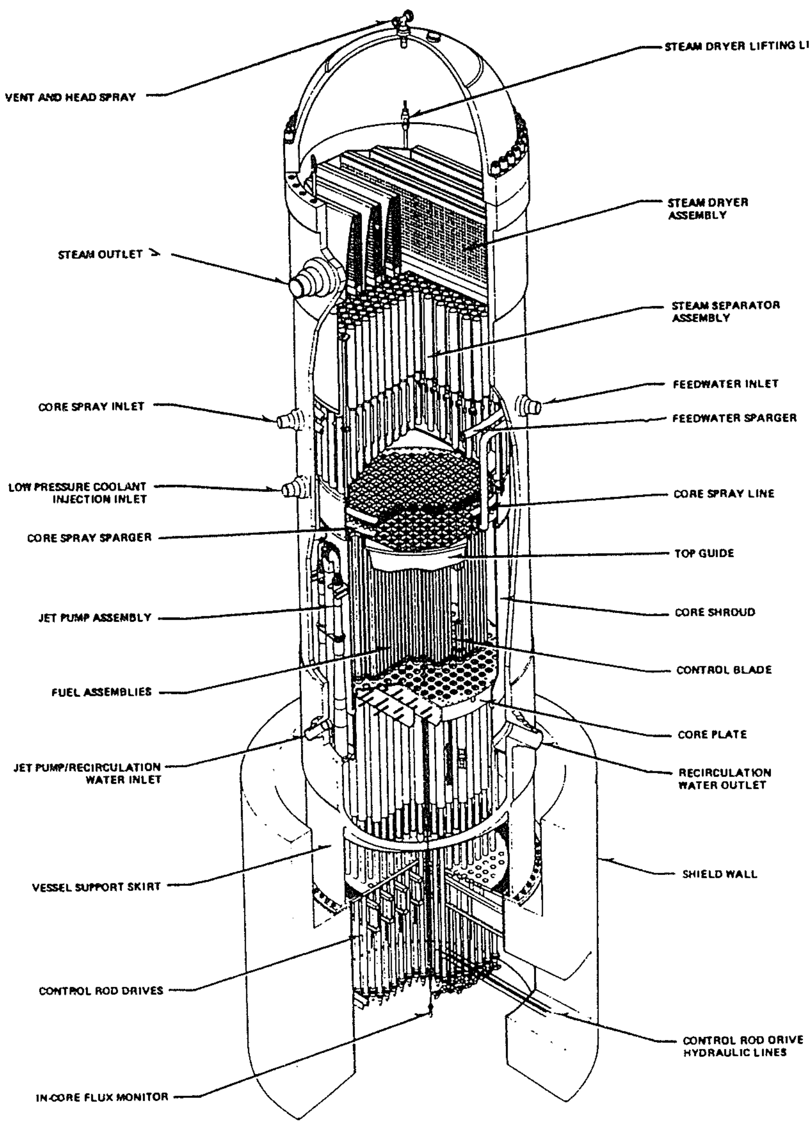


Figure 3
Pressurized Water Reactor Steam Supply System
With U-Tube Steam Generators

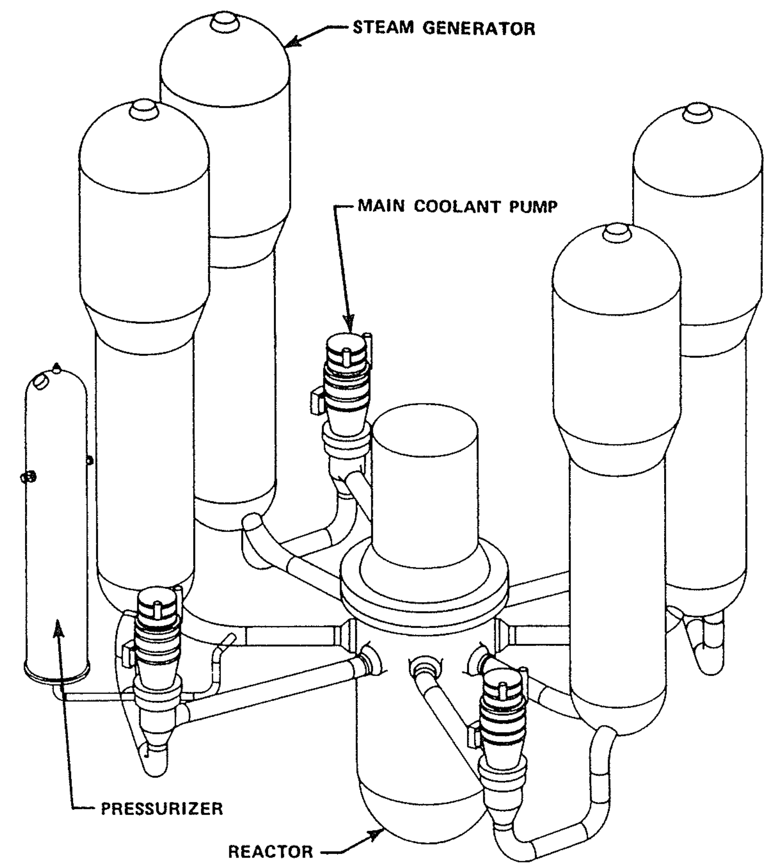


Figure 4
Pressurized Water Reactor Steam Supply System
With Once-Through Steam Generators

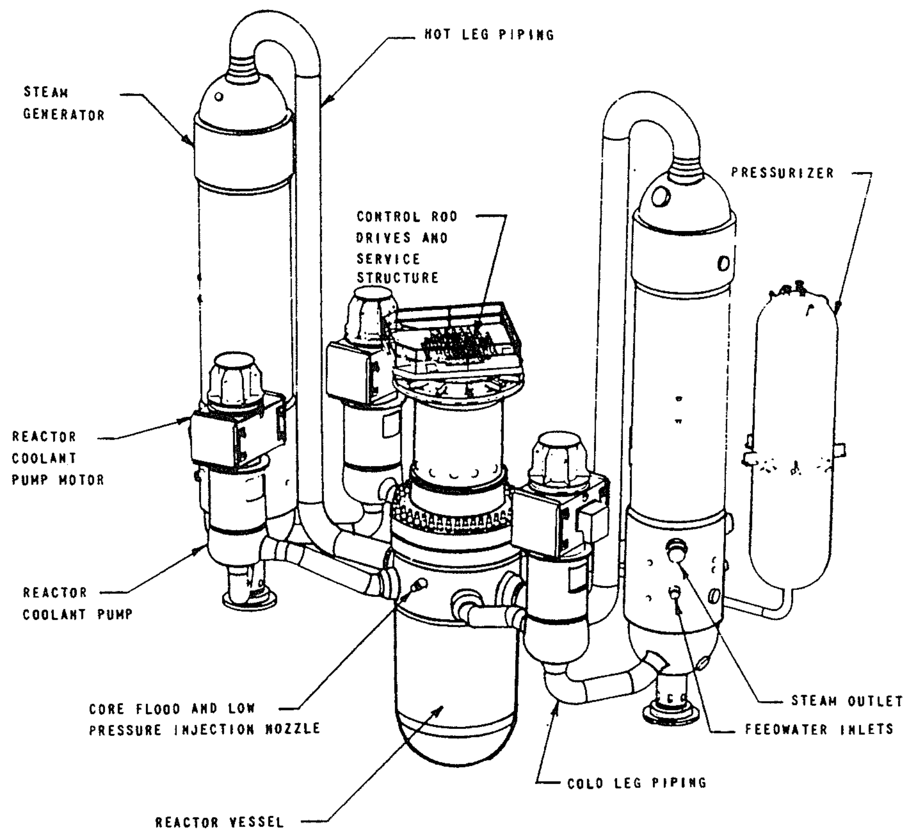


Figure 5
Pressurized Water Reactor Pressure Vessel

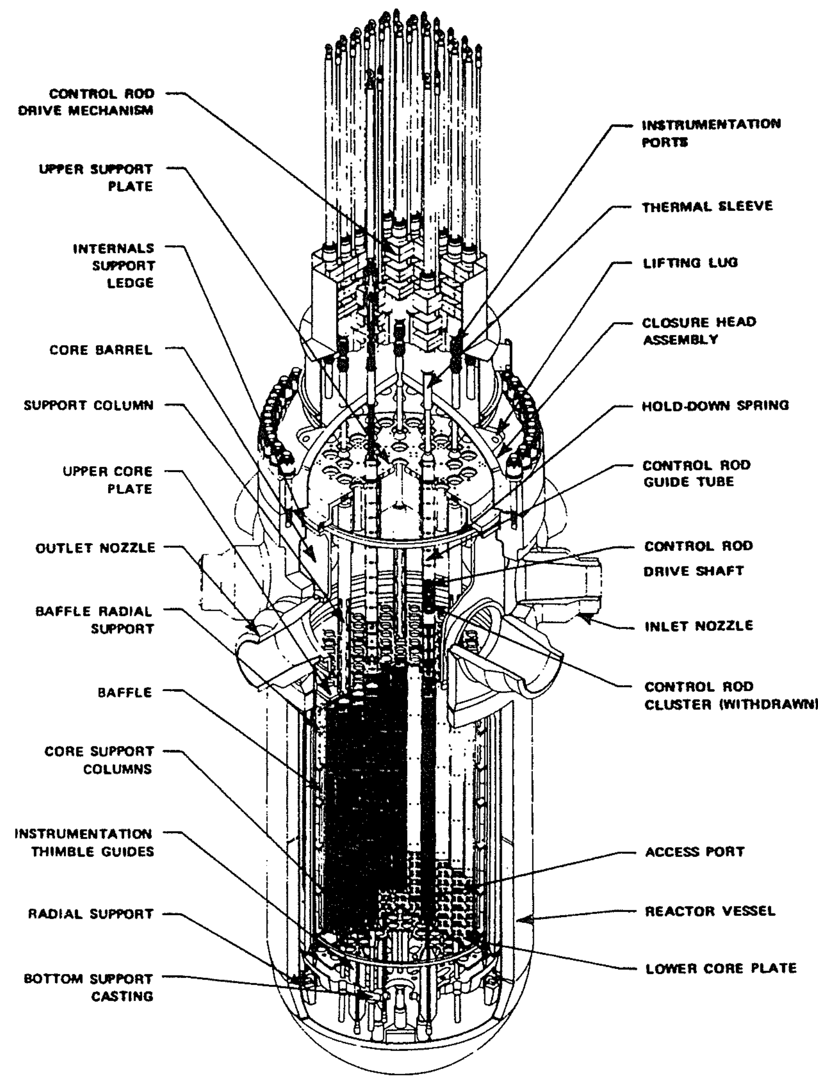
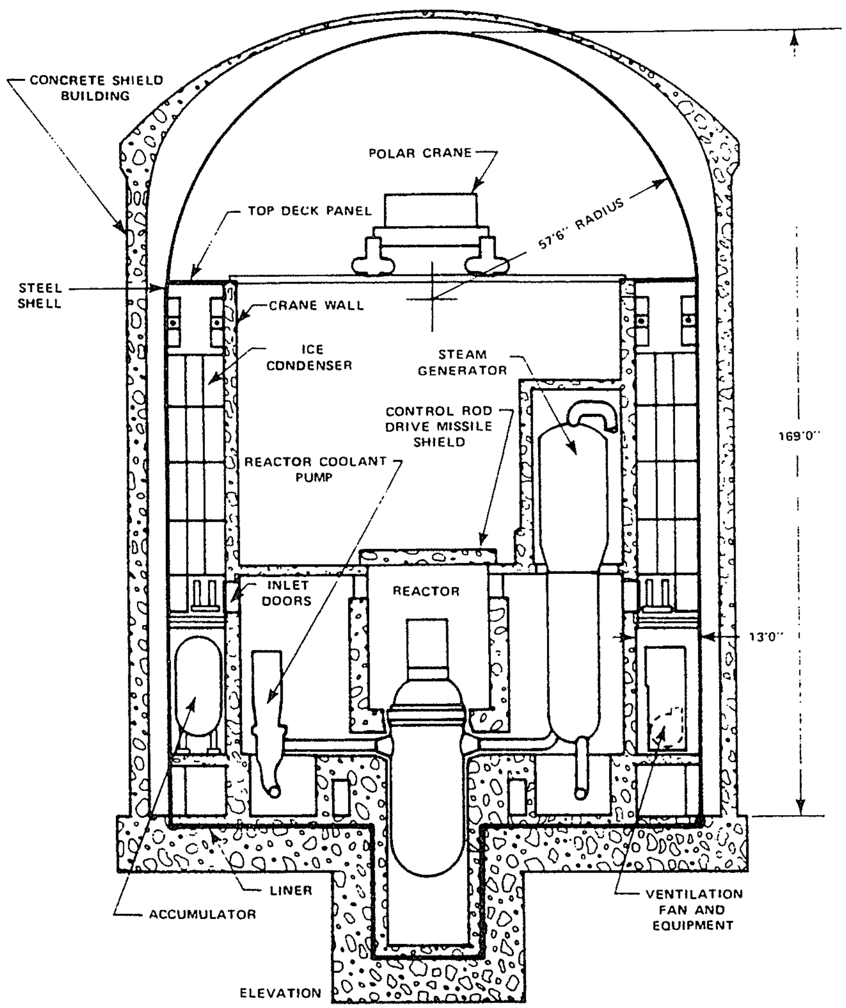


Figure 6
Pressurized Water Reactor in Containment



Neutron embrittlement of the reactor vessel is of current interest at some operating plants, and the subject is already the focus of industry efforts. High levels of copper and nickel impurities in the steel used for some reactor vessel components can make the steel more sensitive to high-intensity, long-term neutron bombardment.

A potential solution to extreme radiation embrittlement is to restore the ductility of the steel through a heat treatment process called thermal annealing. There is increasing interest in the technique. The Soviet Union has experience in limited annealing of reactor vessels. Special heaters have been used at nine Soviet PWR's to raise the temperature of the metal along the vessel beltline welds to 454°C (850°F) for about six days, restoring ductility and toughness that had diminished under high neutron exposure.

YANKEE ROWE LIFETIME EXTENSION

At Rowe, Massachusetts, the country's longest-operating nuclear plant, and one of the best-performing, is gearing up for another run at the record books. The founders of Yankee Atomic Electric pioneered commercial nuclear power in 1954. Yankee has consistently been a standout performer. The plant's capacity factor has exceeded the industry average in all but 2 of the last 15 years and has beat its own lifetime average for each of the last 5 years. Owners of the 175-Mw Yankee Rowe PWR, which started up in 1960-only four years after the decision to build it- expect to file for license renewal in June, 1992.

Preliminary cost-benefit studies for license renewal and extended operation have been conducted at Yankee. The capital cost of running for a 20-year renewal term is $150 per kilowatt of electricity generated. That puts the cost of license renewal at around one-tenth the cost of new coal-fired baseload capacity and makes continued nuclear generation at Yankee competitive over the long haul.

NUCLEAR REACTOR LABORATORY PARTICIPATION IN NUCLEAR POWER REACTOR LIFETIME EXTENSION MATERIALS TEST PROGRAMS

The Nuclear Reactor Laboratory conducts accelerated radiation aging tests for a variety of organizations. Test specimens of reactor vessel structural materials are irradiated in and around the Ford Nuclear Reactor core where they are subjected to combined bombardment by thermal (low energy) neutrons, fast (high energy) neutrons, and gamma rays. Primary interest is in embrittlement caused by fast-neutron-induced distortions in the crystal lattices of those materials.

As metals are reduced in temperature, they reach a point called the nil ductility transition temperature where, if they are subjected to high pressures such as exist within power reactor pressure vessels, they can fail by catastrophic rupture rather than simply stretching as the skin of a balloon would stretch to relieve stress caused by the pressure. This catastrophic failure phenomenon, called brittle fracture, can be duplicated with a wire coat hanger by bending it back and forth rapidly until it breaks.

The hanger does not stretch out and elongate. The bending embrittles the wire so that it severs abruptly with almost no warning when it breaks.

Fast neutron bombardment of a power reactor pressure vessel has a similar embrittlement effect on the vessel steel to reduction in temperature. Prolonged irradiation can effectively increase the nil ductility transition temperature to a level as high as the normal reactor operating temperature, 550°F. Prolonged fast neutron bombardment also creates the potential for catastrophic brittle fracture of the reactor vessel.

Pressure vessel steel specimens from the Yankee Rowe reactor are being irradiated at the Ford Nuclear Reactor. The program details have not been completed, but they may include post-irradiation thermal annealing to restore ductility to the specimens, and re-irradiation to simulate an additional 20 years of service. The lifetime fast neutron dose that would be received by a power reactor pressure vessel far from its core can be simulated by an irradiation of a few weeks or months at the Ford Nuclear Reactor adjacent to its core.

The Nuclear Regulatory Commission and the Department of Energy are sponsoring additional irradiations to gather data on the effects of fast neutrons on weld joints. Welds are particularly subject to brittle fracture because the high temperatures associated with welding create stresses within steels. It seems anomalous that high temperature creates stress and that, if properly applied, it can relieve stress.

Typical test specimens are relatively small, rectangular shapes about the size of pieces of chalk. The specimens are tested to failure either by applying a tensile force and pulling them apart or by applying a rapid impact to make them fail abruptly. A different, though related, program being conducted for the University of California, Santa Barbara, involves irradiation of very small steel discs. The object of this program is to attempt to find a correlation between the increase in disk hardness and the yield strength of the steel which can be tied to nil ductility transition temperature.

A final reactor vessel materials program is being conducted for the Department of Energy through Oak Ridge National Laboratory. In principle, it is similar to the programs described above, but it involves radiation damage tests of reactor vessel and structural materials associated with a new, high temperature gas-cooled reactor design rather than lifetime extension of existing boiling water and pressurized water reactors.

(Based in part on an article entitled "Nuclear Plants: Life After 40," Taylor Moore, EPRI Journal, October/November 1990.)

NUCLEAR REACTOR LABORATORY DIRECTORY

Hours of Operation

Monday-Friday 8:00 a.m. - 5:00 p.m.

Facilities can be made available 24 hours a day, if required.

Tours

Monday-Friday 9:00 a.m. - 4:00 p.m.

Tours should be scheduled at least 24 hours in advance

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