DANTE B. FASCELL
19TH DISTRICT, FLORIDA

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Congress of the United States
House of Representatives
Washington, DC 20515

CHARLES R. O'REGAN
ADMINISTRATIVE ASSISTANT

COMMISSION ON SECURITY AND
COOPERATION IN EUROPE
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NORTH ATLANTIC ASSEMBLY
CHAIRMAN
HOUSE DELEGATION

CANADA—UNITED STATES
INTERPARLIAMENTARY GROUP
MEMBER, U.S. DELEGATION

May 29, 1986

The Honorable Nunzio Palladino
Chairman
Nuclear Regulatory Commission
Washington, D. C. 20555

Dear Chairman Palladino:

Enclosed, for your information, are copies of a letter and enclosures which have come to me from one of my constituents, Ms. Joette Lorion, Director, Center for Nuclear Responsibility, 7210 Red Road, Suite 217, Miami, Florida 33143.

Ms. Lorion has brought to my attention allegations that I would like you to investigate concerning the Turkey Point Nuclear Powerplant located in my Congressional District: 1) that Florida Power and Light Company did not retest the weld metal of Unit 4 either in 1978 or in 1986, but instead used the test data from Unit 3 to predict the safe operation of Unit 4; and 2) that the NRC allows Florida Power and Light to use data from weld metal tests for Unit 3 to predict the actual levels of embrittlement for the vessel that houses Unit 4.

When the embrittlement problem at Turkey Point Nuclear Powerplant first came into the public eye, I expressed concern to you about this potential problem. I would appreciate your consideration of the points raised by Ms. Lorion, and your providing me with the benefit of a reply.

Sincerely,

Dante Fascell

DANTE B. FASCELL
Member of Congress

DBF/rt

CENTER FOR NUCLEAR RESPONSIBILITY
7210 Red Road • Suite 217• Miami, Florida 33143 • 661-2165

May 21, 1986

Congressman Dante B. Fascell

Dear Congressman Fascell:

As per your request, I am sending along information about the problem of pressure vessel embrittlement at Florida Power and Light's (FPL) Turkey Point Nuclear Reactor Units 3 and 4, in South Dade.

Recent events in the Soviet Union lend urgency and great practical significance to your consideration of the materials presented here. The explosion and fire at the Chernobyl nuclear power reactor Unit #4, demostrates, not only that accidents previously considered incredible can, and do occur, but that the permanence of the cost of such catastrophic nuclear accidents in terms of loss of life and property, make the risk of such a nuclear accident intolerable.

It is in this context that I wish to state that my research over the past six years has lead me to conclude that although the nuclear technology at Turkey Point differs somewhat from that of the Soviet reactor, there are unique problems at Turkey Point that pose an unacceptable risk to the people of South Florida.

The two Turkey Point nuclear reactors, units 3 and 4, are suffering from an irreversible condition known as reactor pressure vessel embrittlement. Over the years, radiation has weakened the welds of the large steel pressure vessels that surround the fuel cores and hold the cooling water for the Turkey Point nuclear reactors. An NRC safety engineer has warned that cooling the reactor quickly in an accident could cause the vessel welds to rupture, releasing all the cooling water. NRC officials have stated that if a reactor pressure vessel ruptures, there would be no way to preven t the most feared reactor accident, a meltdown. (See item 1).

One NRC safety engineer, Demetrios Basdekas has been attempting to warn the Commission and the public about the severity of this problem for many years. (See item 2 and 3). He was successful in drawing the NRC's attention to the public and in 1981, the NRC sent FPL a letter stating that the fracture toughness of some reactor pressure vessels was approaching levels of concern. They named Turkey Point Unit 4 as one reactor they were concerned about (See item 4). In 1982, the NRC issued a report on Pressurized Thermal Shock, Turkey Point Units 3 and 4 were listed as having the second and third most brittle vessels out of all the plants reviewed. (See item 5).

We, at the Center for Nuclear Responsibility, now an organization of over 300 saupporters, have been working in the Courts since 1981 in an attempt to get a full public hearing on the Turkey Point pressure embrittlement issue. Research for this litigation led us to critical

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documents that report on the only tests of the weld metal ever performed on Turkey Point Units 3 and 4.

One of these documents, a report by Southwest Research Institute (SWRI), which reports on Charpy tests (See item 1) performed on Unit 4, states that the weld material in unit #4, was 30% more brittle than reported in the Turkey Point Final Safety Analysis Report (FSAR). It also recommends that another weld metal test be performed in 1978. (See item 6a). Another report by SWRI compares Turkey Points units 3 and 4 and shows that after 10 effective full power year (EFPY) of operation, the predicted reference temperature (RTNDT) for Unit 4 would be 342°F, 30% higher than that predicted for Unit 3. (See item 6b).

(Note: The NRC has set a 300° reference temperature unit as a screening criterion beyond which they cannot predict safe operation of the reactor pressure vessel). (See Item 7).

FPL did not retest the weld metal of Unit 4 in 1978. They, in fact, did not test the weld metal in 1986, as they were required to do. In addition, about 1981, the NRC began to use the test data from Unit 3, the less severely affected reactor unit, to predict the safe operation of Unit 4. (See item 8), a practice which an independent scientific expert, Dr. George Sih, Director of Fracture Mechanics, at Lehigh University, calls scientifically invalid. Dr. Sih also charted the SWRI information and showed that according to the SWRI data, Turkey Point Unit 3 had probably exceeded the point of safe operation (NRC screening criterion of 300°) about 1981. (See items 9a and 9b).

The Nuclear Regulatory Commission sanctioned FPL's legal alchemy in 1985, when they issued an ammendment allowing FPL to postpone testing of the Turkey Point Unit #4 for 12 more years (See item 10). And, to this day; the NRC continues to allow FPL to use data from weld metal tests for Unit #3 to predict the actual levels of embrittlement for the vessel that houses Unit #4, a practice which Dr. Sih says is invalid.

It is just this kind of reasoning concerning the safety of the O-ring seals in Challenger, that allowed Morton Thiokol and NASA to sign off the launch of the ill fated space mission. It is even more disturbing in the area of nuclear power regulation, where even a small lapse in rational decision making may have profoundly devastating effects on the public health and safety.

We are providing you with these disturbing facts in hopes that you will see fit to start an investigation into the degree of embrittlement at the Turkey Point nuclear power plant, which is a much closer threat to our health and safety than the nuclear reactors in Cuba. We are also asking you to put pressure on the NRC to force FPL to perform the long overdue weld metal tests on Turkey Point Unit #4.

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And, we would hope that you would make any results of your efforts available to the public. The people of South Florida have a right to know the degree of risk they are exposed to as a result of operation of the embrittled Turkey Point nuclear reactors.

Should you have additional questions, please feel free to call me. My attorney, Martin Hodder, and I, would be happy to meet with you at any time to discuss our research.

Sincerely,

Joette Lorion

Joette Lorion
Director

INVOLVEMENT • LITIGATION • NUCLEAR INFORMATION

Background Sheets

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PRESS/FOR IMMEDIATE RELEASE
MIAMI/OCTOBER 24, 1985

INFORMATION: JOETTE LORION 661-2165
MARTIN HODDER 751-8706

IS TURKEY POINT 4 RUNNING ON BORROWED TIME ?

THE CENTER FOR NUCLEAR RESPONSIBILITY REVEALED EVIDENCE THAT THEY FILED THIS WEEK WITH THE U.S. COURT OF APPEALS IN WASHINGTON. THE EVEIDENCE SHOWS THAT TESTS PERFORMED FOR FLORIDA POWER & LIGHT COMPANY ON THE WELD METAL OF UNIT 4, INDICATE THAT TURKEY POINT NUCLEAR UNIT 4 HAS PROBABLY EXCEEDED THE DANGER POINT SET BY THE NUCLEAR REGULATORY COMMISSION (NRC) FOR SAFE OPERATION OF PLANTS WITH BRITTLE REACTOR PRESSURE VESSELS. (The NRC has admitted that Turkey Point 4 has the 2nd most brittle pressure vessel in the entire U.S., susceptible to cracking and a subsequent core meltdown in an accident that requires cold water be pumped in to cool the core)
AT A NEWS COFERENCE TODAY, REPRESENTATIVES OF THE CENTER DISTRIBUTED PAGES FROM A 1976 REPORT PERFORMED BY THE SOUTHWEST RESEARCH INSTITUTE FOR FPL THAT SHOWED THAT THE WELD METAL IN THE PRESSURE VESSEL OF TURKEY POINT 4 WAS 30% MORE BRITTLE THAN THAT IN UNIT 3; AND THAT ACCORDING TO THE INSTITUTE'S PROJECTIONS, UNIT 4 WOULD REACH THE NRC'S BRITTLE TEMPERATURE LIMIT of 300° F WELL BEFORE 10 EFFECTIVE FULL POWER YEARS OF OPERATION. THE CENTER ALLEGED THAT BOTH THE NRC AND FPL IGNORED THIS CRUCIAL DOCUMENT, AND OPTED FOR LEGAL ALCHEMY - USING UNIT 3 DATA TO PREDICT CONTINUED SAFE OPERATION FOR UNIT 4.

THE CENTER ALSO MADE PUBLIC A LETTER FROM DR. GEORGE SIH, NOTED METALLURGIST AND DIRECTOR OF FRACTURE MECHANICS AT LEHIGH UNIVERSITY, TO CONFIRM THEIR POSITION. SIMPLY SUMMARIZED, THE LETTER CONFIRMS:
(1) THE USE OF UNIT 3 TEST DATA TO PREDICT THE RATE OF EMBRITTLEMENT AND CONTINUED OPERATION OF UNIT 4 IS INVALID; (2) PROJECTIONS BASED ON THE 1976 FPL REPORT INDICATES THAT EMBRITTLEMENT AT UNIT 4 HAD EXCEEDED THE DANGER POINT OF 300°F SET BY THE NRC ABOUT 1981;
(3) PROJECTIONS FROM THE SAME DATA SHOW THAT UNIT 4 COULD REACH 450°F DURING THE PLANT'S LIFE.

THE CENTER ALSO CHARGED THAT THE NRC HAS CONFIRMED FPL'S ALCHEMY BY ALLOWING THEM TO DEFER A UNIT 4 WELD METAL TEST SCHEDULED FOR THIS YEAR FOR FOURTEEN MORE YEARS, UNTIL THE YEAR 2,000.

BACKGROUND SHEET

The trouble at Turkey Point is this: the large steel pressure vessels that surround the nuclear fuel cores and contain the reactors' cooling water were designed so that they should never crack during the reactors' 40 year lifetime. But, age and radiation damage have caused the copper welds of the Turkey Point Unit 3 and 4 nuclear power plants to become brittle. So brittle that the U.S. Nuclear Regulatory Commission has admitted that Turkey Point Units 3 and 4 have the second and third most brittle vessels in the entire United States. This means that they are susceptible to cracking if an emergency occurs that requires FPL to pump cold water into the vessel. The shock of the cold water could cause the hot brittle vessel to crack, much like a hot glass would if it was dunked in cold water. A crack in the vessel could cause the cooling water to escape and result in a core meltdown, the most feared reactor accident.

The metal and welds in a nuclear reactor pressure vessel can respond to abrupt changes in temperature and pressure (such as you would experience in an accident) with either ductile or brittle behavior. Ductility is the ability of the reactor metal and the welds to withstand stress without cracking. In a new nuclear reactor the metal is extremely ductile. The metal in a new vessel can be easily cooled from the reactor's normal operating temperature of 550°F to 0-40° without cracking. But as time goes on, the weld metal becomes increasingly brittle even at high temperatures in the 200°-300° range.

The Nuclear Regulatory Commission has named the temperature at which the metal or metal welds stop being ductile and become brittle the TRANSITION TEMPERATURE (RTNDT). The NRC has also set a point at which the transition temperature in a given reactor would be a cause for concern. THE NRC BRITTLE TEMPERATURE LIMIT, OR DANGER POINT, HAS BEEN SET AT 300° F. These high brittle temperature limits are dangerous because the reactor vessel has to be maintained at these temperatures if the effects of brittle metal are to be avoided. Thus, any incident which results in abrupt pressure and temperature changes and requires quick cooling below 300° F could result in a pressure vessel rupture in a severely embrittled reactor. According to Robert Pollard of the Union of Concerned Scientists, "the greatest danger of brittle fracture exists while the plant is starting up, cooling down, or during accidents."

The degree of embrittlement in the vessel welds can be measured by taking metal samples out of the reactor and testing them. Reports of tests performed on Unit 3 and Unit 4 weld metal in 1975-76 by Southwest Research Institute showed that the Unit 4 weld metal was 30% more brittle than Unit 3; and that Unit 4 was scheduled to reach the NRC danger point of 300°F around 1981. However, FPL appeared to ignore these results and continues to use Unit 3 data to predict continued safe operation of Unit 4. FPL has also refused to perform weld metal tests scheduled for this year, and has received a license amendment which allows them to put off these critical tests for fourteen more years. WHY?

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THE TROUBLE AT TURKEY POINT

The Turkey Point nuclear power plant, located 25 miles from Miami, has problems. It has been named by the Nuclear Regulatory Commission, agency in charge of nuclear safety, as having the second and third most brittle reactor pressure vessels in the entire United States. Over the years, radiation has caused the huge steel domes that surround the core (radioactive fuel) of these nuclear reactors to become brittle. The danger is that should an accident occur at Turkey Point that requires cold water to be pumped into the core to cool it, the shock of the cold water on the hot, brittle metal could cause it to crack (much like a hot glass would if you dunked it in cold water). If this condition, known as pressurized thermal shock were to occur, there would be no way to cool the reactor. The result would be a core meltdown, the most feared reactor accident. Such an accident, according to a 1982 Sandia Labs Report commissioned by the NRC,'would kill 29,000 people in a ten mile radius of the plant, injure 45,000 people in a 70 mile radius, cause 48.6 billion dollars in property damage, and contaminate much of South Florida for hundreds of years.

THE FOLLOWING FACTS ABOUT PRESSURE VESSEL EMBRITTLEMENT AND PRESSURIZED THERMAL SHOCK ARE IMPORTANT FOR THE PEOPLE LIVING IN THE AREA OF TURKEY POINT TO KNOW:

1. THE NUCLEAR REGULATORY COMMISSION (NRC) HAS SINGLED OUT TURKEY POINT AS A PLANT WITH SEVERE EMBRITTLEMENT PROBLEMS. On August 21,1981, the NRC advised FPL that reductions in fracture toughness for reactor pressure vessels at some plants "are approaching levels of concern." They went on to ask FPL to provide information as to why Turkey Point's operating license should not be "modified, suspended, or revoked."

2. THERE ARE NO SAFETY SYSTEMS AT TURKEY POINT TO PROTECT THE PUBLIC FROM A PRESSURE VESSEL RUPTURE. All safety systems in the nation's nuclear power plants were designed on the premise that a pressure vessel rupture was an "incredible event" that could never happen. The NRC is now agreeing that such an accident could occur, but they still have no safety systems designed to deal with such an event.

3. FROM 1963-1981, THERE HAVE BEEN 85 INCIDENTS AT AMERICA'S NUCLEAR PLANTS THAT COULD HAVE RESULTED IN THERMAL SHOCK. According to a 198[illegible] report that was publicized by Congressman Edward J. Markey, many of these incidents could have resulted in a major nuclear accident if the reactors had been older. For instance, an over pressurization accident that took place at the Rancho Seco plant in 1978, could have cracked the vessel if the plant had been ten years old. Turkey Point is nearing the ten year mark.

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4. A NUCLEAR ENGINEER WARNS THE PUBLIC. A Nuclear Regulatory Commission reactor safety engineer, in both a N.Y. Times Editorial and a letter to Congressman Morris K. Udall, warned that the people living close to the most severely embrittled nuclear plants were in danger of the "most feared reactor accident", a core melt, taking place. Basdekas urged that all reactors with over 4 years effective full power operation be shutdown until the matter "is resolved in the technical arena."

5. THERE IS NO CURE FOR PRESSURE VESSEL EMBRITTLEMENT. The pressure vessel is "the heart" of the nuclear reactor and cannot be replaced. Once the vessel has become brittle, there is no way to stop this "nuclear cancer process". The plant will continue to operate until it reaches the danger limit set by the NRC. Original NRC estimates for reaching that limit could have shut down Turkey Point by July of 1988.

6. THE NRC AND FPL EXPERIMENT IN THE FIELD, RATHER THAN THE LABORATORY. In the past few years, in an attempt to slow down the embrittlement, the NRC has passed a series of license amendments that allows FPL to experiment with the embrittlement problem. These licensing changes, which include a redesign of the reactor core, could result in "hot spots", which some scientists say could lead to overheating of the reactor and the meltdown that the NRC is trying to prevent. These amendments, which admittedly lowered safety at the plant, were passed without the required public hearings.

7. TURKEY POINT WILL BECOME INCREASINGLY EXPENSIVE. As the Turkey Point reactors near the NRC's "danger point", they will have to be derated (run at lesser power). The cost of redesigning the two reactor fuel cores at Turkey Point is $25 million per reactor. The cost of derating these same reactors will be $25 million per reactor per year. Once again, the consumers will pay for the nuclear industry's failures.

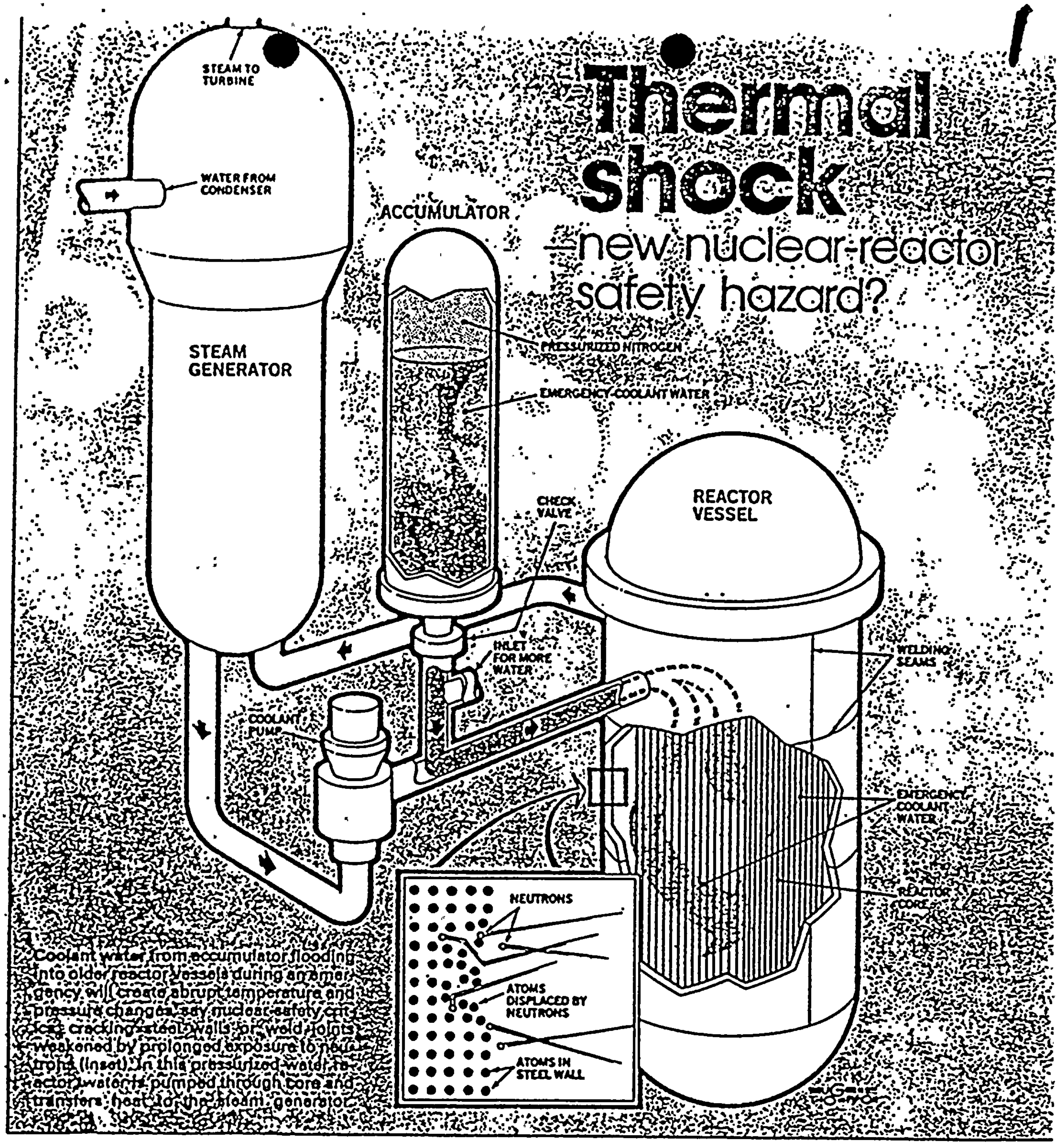
8. FOR THOSE OF YOU WHO THINK THAT THE NRC IS WATCHING OUT FOR YOUR SAFETY: A 1984 GAO Report to Congress entitled, " Management Weaknesses Affect Nuclear Regulatory Commission Efforts to Address Safety Issues Common to Nuclear Power Plants," The NRC "does not have sufficient management controls in place sufficient to ensure resolution of issues and implementation of appropriate changes to affected nuclear plants, and to NRC regulations in a timely manner." They state that at the NRC's current level of effort, it will take about 10 years to eliminate the backlog of unresolved safety issues. (Pressure Vessel Embrittlement has been an unresolved safety issue since 1978).

CAN WE AFFORD TO WAIT?

THE CENTER FOR NUCLEAR RESPONSIBILITY, A NON-PROFIT EDUCATIONAL ORGANIZATION, BELIEVES IN CITIZEN INVOLVEMENT IN NUCLEAR SAFETY ISSUES THAT AFFECT OUR LIVES. WE ARE CURRENTLY INVOLVED IN LITIGATION BEFORE THE U.S. COURT OF APPEALS, THE U.S. NUCLEAR REGULATORY COMMISSION, AND THE U.S. SUPREME COURT. WE ARE LITIGATING THE ISSUES OF PRESSURE VESSEL EMBRITTLEMENT, NUCLEAR WASTE DISPOSAL, AND CITIZEN PARTICIPATION IN NUCLEAR ISSUES. WE WELCOME MORAL AND FINANCIAL SUPPORT. Please send tax-deductible donations to CNR, 7210 Red Rd #208, Miami, Fl. 33143. Make payable to Community Intervention Turkey Point Project.

*Sources for all of the above facts are available on request.

Thermal shock
—new nuclear-reactor safety hazard?



Coolant water from accumulator flooding into older reactor vessels during an emergency will create abrupt temperature and pressure changes, say nuclear-safety critics, cracking steel walls or weld joints weakened by prolonged exposure to neutrons (inset). In this pressurized-water reactor, water is pumped through core and transfers heat to the steam generator.

Could cooling water rupture brittle reactor walls? Here are the facts

By EDWARD EDELSON
DRAWING BY EUGENE THOMPSON

"There is a high, increasing likelihood that someday soon, during a seemingly minor malfunction at any of a dozen or more nuclear plants around the United States, the steel vessel that houses the radioactive core is going to crack like a piece of glass. The result will be a core meltdown, the most serious kind of accident, which will injure many people, destroy the plant, and probably destroy the nuclear industry with it."—Demetrios L. Basdekas, *The New York Times*, March 29, 1982.

Basdekas, a reactor-safety engineer with the Nuclear Regulatory Commission, continued his article to warn that radiation is making the metal reactor vessels at some nuclear plants brittle. As a result, he wrote, water used to flood and cool reactor cores in an emergency could cause a meltdown instead of preventing one. The cause: abrupt changes in reactor pressure and temperature—a condition called pressurized thermal shock—would crack brittle vessels, allowing emergency water to escape.

The safety engineer's "piece-of-glass" charge quickly focused attention on thermal shock:

• The NRC commissioners held a public meeting.

• Rep. Ed Markey of Massachusetts called a congressional hearing.

Continued

• Work on what was supposed to be a definitive study of the thermal-shock issue was accelerated by the NRC.

And the kind of debate that has become quite familiar in recent years has predictably erupted. Electrical utilities, reactor manufacturers, and the Nuclear Regulatory Commission say that the pressurized-thermal-shock problem is well in hand and that the "piece-of-glass" charge is absurd. Critics say that the nuclear people are talking through their hats because there simply isn't enough information available to assess the danger of pressurized thermal shock.

I've recently talked to experts on both sides of the question. At the moment there are no pat answers. But information about the hazard of thermal shock is accumulating steadily. Here is what you need to know.

Pressurized thermal shock has been widely publicized only recently. But inklings of a problem emerged in the 1960s.

At one power-plant reactor, a worker peered into a video monitor and manipulated a robotic arm down into the radioactive water of a 40-foot-high reactor vessel. He slowly fished out a small basket hanging near the thick metal wall of the reactor. Inside the basket was a jumble of pencil-size steel bars, each alloyed with various metals and each bearing a V-shaped notch.

At a nearby test area, he carefully unloaded his irradiated catch behind shielded-glass windows. Deft maneuvers with another robotic arm positioned each steel bar under a wedge-shaped hammer. Then, as samples were cooled or heated, he pushed a button, and the hammer slammed into the notches.

This routine Charpy test (named for its developer) yielded expected results: At lower temperatures, where metals become brittle, samples broke easily. Higher temperatures—like those in your kitchen oven—made the steel more ductile. Heated steel samples absorbed more hammer energy before snapping.

But something unexpected occurred when the worker slammed his test hammer onto bars alloyed with tiny amounts of copper. The steel—even warmed—broke easily. He raised the temperature. Still the brittle bars snapped. Finally at about 300 degrees F, the bars became ductile instead of brittle. The presence of copper seemed to be producing strange results. Soon workers at other power and research reactors discovered the same unexpected embrittlement.

What puzzled everyone was the speedup of embrittlement because of the presence of copper, not the results of the standard Charpy tests on exposed metal samples. This technique—gradually changing metal temperatures and measuring how much hammer energy the metal can absorb without breaking—actually tests radiation damage. Radiation tends to make all metals brittle; irradiated metal must be raised to a higher temperature before it will become ductile. This shift in the transition temperature from brittle to ductile is a measure of radiation damage.

Nuclear researchers, aware of metal embrittlement, had earlier exposed samples to intense radiation. But the surge of reactor construction beginning in the 1960s found engineers without enough reliable data. To answer questions about long-term radiation effects on metal, baskets of Charpy samples had been positioned in early reactors.

> "Copper was used to prevent rust. Someone probably got a prize for the suggestion"

The principal cause of embrittlement was known to be neutrons, the atomic particles emitted by nuclear fission in the reactor core, colliding with metal in the reactor. "It's like billiards," says one expert. "Although metal atoms are much heavier than neutrons, when a high-energy neutron collides with a metal atom, the neutron forces the atom from its lattice—the geometric array of atoms."

The Charpy tests of the 1960s revealed that just a little copper in a steel alloy hastens embrittlement. Since that time, though, researchers have been uncertain why the presence of copper hastens radiation damage. Theodore U. Marston, who works on thermal shock at the Electric Power Research Institute in Palo Alto, Calif., says there's now strong evidence that neutron bombardment makes the copper clump together.

"Copper starts out in a solid as atoms fairly evenly distributed. Under radiation the atoms tend to come together as copper particles," he said. New instruments that let researchers see atoms within metals show this clumping effect, Marston says.

As the first discoveries of brittle irradiated steel containing copper became known, anxiety began to spread. How much copper was in the steel-alloy walls of reactor vessels across the country? Reactor vessel manufacturers and utilities began leafing through old files to find what information they had about the copper content of metals in reactors.

Records showed that there was some copper in the vessel walls themselves. "We used a lot of auto stock," explained Marston. "When you melt it, you can't get all the wiring out."

But welds in vessel walls were the real problem. Before the industry realized what was happening, which was about 1972, spools of copper-coated welding wire were routinely used for these welds. "The copper was used to prevent rust," noted Stephen H. Hanauer, director of safety technology at the NRC. "Someone probably got a $10 prize for the suggestion."

Reactor builders switched to nickel-coated electrodes, but they couldn't replace the welds in older reactors. When I visited Marston last winter, the significance of those welds became clear. On his desk was a slab of metal that looked like a paperweight gone wild. I thought it was eight inches wide. But it was really eight inches thick—the thickness of a reactor-vessel wall. The weld was a yellowish stripe in the steel, tapering from three inches thick on one side to two inches on the other. Marston told me that it can take three weeks of repeated passes with electrodes to complete one of those welds. That type of weld, engineered to be a powerful bond between huge steel sections of reactor vessels, contained enough copper to become a potential hazard instead.

Interest in reactor-vessel embrittlement heated up in 1977, Marston recalls. There was trouble with the sample holders in a reactor built by Babcock and Wilcox, one of the major suppliers, he says. Vibration kept knocking them loose. All the samples were taken out, and "it looked worse than we thought," Marston said, indicating that embrittlement was progressing faster than expected in the test samples.

Added to this continued confirmation of embrittled-metal samples and copper contamination of vessels was an event the following year that, for some, increased the alarm.

On March 20, 1978, a worker at the Rancho Seco nuclear generating plant near Sacramento, Calif., dropped a light bulb into an instrument panel. The panel shorted out and the plant's instruments went haywire, flashing fake signals to the control systems. Rancho Seco's emergency cooling system kicked into operation. Cold water

Continued

flooded into the reactor, dropping the temperature from 582 degrees F. to 285 in a little more than an hour.

Pressure inside the reactor vessel first dropped from the normal 2,200 pounds per square inch to under 1,600 psi. Then, as high-pressure water pumps were triggered, the pressure went back over 2,000 psi. With no reliable instrumentation to guide them, control-room technicians kept the cold water flowing, maintaining the combination of unexpectedly low temperature and high pressure for several hours.

The Rancho Seco "transient," as nuclear engineers call it, made it clear that pressurized-water reactors were susceptible to abrupt changes in temperature and pressure. Could any pressurized reactors already have small cracks? And could vessel walls containing such cracks, subjected to sudden changes of temperature and pressure during an accident, then rupture, draining the coolant water and producing a catastrophic meltdown of the core?

The truth is that nobody knows for certain. Calculations indicate that under pressurized-thermal-shock conditions, a reactor vessel will fail only if cracks of a certain dimension are present on the inside wall. Inspections throughout the industry have used ultrasound and other nondestructive testing methods and thus far have found no such cracks. Industry representatives say they are reasonably confident that no cracks are there. Critics say the inspection equipment isn't good enough to detect the cracks. The NRC says its analyses assume that some cracks exist, no matter what inspections show.

Richard Cheverton of the Oak Ridge National Laboratory, whose team has performed many of the thermal-shock analyses, says assumptions about weaknesses in nuclear power plants had to be made. Take the critical issue of cracks in the reactor-vessel walls. "It's difficult to look for flaws after the reactor is in operation, and it's still a question of how good a job one can do," Cheverton said. "It's not clear yet whether some of the shallow flaws that can get us into trouble can be found with accuracy, so we tend to assume that the flaws will be there."

But Richard J. Sero, who heads a program on thermal shock for Westinghouse (a major plant builder), maintains that there is growing evidence to support the belief that the cracks aren't there. Engineers often inspect working-reactor vessels with ultrasound equipment, whose echoes are analyzed to detect anything unusual in the vessel wall—a crack, an inclusion of different material in the metal, an unevenness in the surface.

Ultrasound inspection is complicated somewhat by the fact that reactor vessels have a ¼-inch-thick cladding—a permanently bonded layer—of stainless steel on the inside surface that can produce false echo patterns. But that's not an insuperable problem. Sero says he's impressed by the sensitivity of the equipment.

"We've done about a half-dozen full-vessel inspections," Sero said. "You do pick up what we call 'indications'—as many as 20 in some vessels. When you pick up any anomalies at all, you must look at your pre-service inspection to see if they existed before and what size they were.

"We've found that the equipment can pick up things like layers in the cladding," Sero continued. "When we've gone to the inspection reports, we've found that there are layers in the cladding at the same depth of the indication. Our conclusion is that in all the inspections we've done, we haven't found any indications that we can't resolve as inclusions of different material or layers."

> "The NRC may consult its Ouija board and get a number, but the error bands are so large, it's useless"

Sero says Westinghouse gained confidence in the inspection results when one test showed a gouge on the outside wall of a reactor vessel. "We were able to get pictures of the reactor vessel that were taken before it was installed," he said. "We found that it was a gouge that existed before it went to the plant." A sample of a vessel wall containing a crack is used to calibrate instruments.

The NRC recently released a detailed study on pressurized thermal shock and reactor safety. If you really want a good fight, ask people about the reliability of those safety estimates. The method the NRC and the industry uses is called probabilistic risk assessment. It's designed to get around a rather impressive lack of concrete evidence. All the calculations about pressurized thermal shock, for example, are based on just eight events that have occurred at nuclear plants, including the Rancho Seco transient and the most famous incident of all, Three Mile Island.

In a probabilistic risk assessment, you estimate the likelihood of an event that initiates a transient, then estimate the likelihood of the reaction to that event, the reaction to that reaction, and so on down the line.

Westinghouse, for example, has a computer analysis that starts with 17 possible initiators and runs through event trees to more than 8,200 end points. The NRC has done the same thing. Its numbers come out more or less in agreement about the risk of thermal shock. But there are inevitable differences of opinion about the value of those calculations, which show that although there is no clear and present danger, corrective action should be taken at some reactors to reduce the hazard of thermal shock.

Not everyone agrees with the calculations. "The NRC may consult its Ouija board and come up with a number," said Robert Pollard of the Union of Concerned Scientists, "but the error bands on it are so large that it's essentially useless."

That's not exactly so, says Cheverton of Oak Ridge. "It's possible to estimate what the uncertainty in the analysis is, and you have to live with that uncertainty," he said. "But you take the conservative end of it and work with that."

A lack of data is more or less conceded all through the NRC report. "Perhaps the most significant uncertainty in the treatment . . . is that there are known low-frequency potential over-cooling events much more severe than those that have occurred," the report says at one point. "Because these events have not occurred, they have not been taken into account in the frequency distribution." In other words, it's tough to predict the possibility of something that has never happened. In another section, the report notes "substantial uncertainties" in some estimates and calculations that are uncertain by "plus or minus at least two orders of magnitude, a broad band of uncertainty, indeed."

What else can we do? the NRC people ask. "It isn't well defined, but it's the best information we have," said the NRC's Hanauer.

Your best is none too good, the critics say. They point out that the probabilistic-risk-assessment technique is the same one used in the famous Rasmussen report of 1974, in which a team headed by MIT professor Norman Rasmussen calculated the risks of nuclear accidents. Rasmussen came up with some comfortingly low-risk figures. Just last year, though, the

Continued

NRC looked over the operating data that have accumulated since then and concluded that the odds of a nuclear accident occurring calculated by Rasmussen were low by a factor of 30.

Hanauer says that risk calculators have learned a lot from Rasmussen's pioneering effort. "He kissed off earthquakes in two pages and floods in two lines," Hanauer noted. Taking one volume of a shelf-long safety assessment of the Indian Point reactor near New York City, Hanauer pointed out that earthquakes and floods were toward the top of the list of risks. The NRC has learned to include such risks in its risk assessments, Hanauer says.

But Basdekas dismisses the report as "the quantification of wishful thinking." And George Sih, director of the Institute of Fracture and Solid Mechanics at Lehigh University, says that the impressive report is built on a foundation of sand.

"The samples they study are five inches long, and the vessels are 500 inches long," Sih said. "The sample is very thin, and the vessel is eight inches thick. We don't know how to transfer small-sample data to the design of large-scale structural components. The scaling effect in size and also the scaling effect in time are among the most difficult questions we have."

If critics think the NRC has been too speculative, industry believes the report is too conservative. You can arrive at just about any conclusion you want by putting in the appropriate numbers, Marston says. "By changing the assumptions," he explained, "I can show that one of these things has no useful life at all or a lifetime of 30 to 40 years." The NRC consistently takes the most conservative numbers for its estimates, he says.

One of the key factors that the NRC's experts looked at was the transition temperature at which a piece of metal stops being ductile and becomes brittle enough to break easily. A crucial part of the NRC report was to set a point at which this transition temperature in a given reactor would be cause for concern. The report sets the danger point at 300 degrees F for vertical welds, 270 degrees for horizontal ones.

Higher transition temperatures are worse, since the reactor vessel must be maintained at these temperatures if the effects of brittle metal are to be avoided. The original standard for nuclear reactors was no more than 200 degrees F. The temperature is higher for vertical welds because pressure tends to force the welds out, increasing the possibility that a crack will break through the vessel wall.

Determining a transition temperature depends on the composition of a metal, the amount of radiation it receives, and, most controversially, the stresses to which it is exposed. The NRC staff used a formula to predict how assumed pre-existing cracks might extend into the vessel wall.

As a result of tests on the rate of embrittlement at various plants, the NRC predicted when some of them will reach a danger point. All things considered, the NRC report reached a reasonably comforting conclusion. It listed 40 pressurized-water reactors in which pressurized thermal shock was an issue. "If no one does anything, we've got one reactor that's in big trouble, four others that are a little behind it, and four that are in a mild kind of trouble," Hanauer told me. "The rest of them will not reach

> "Though the inner portion is brittle, the outer portion is tough; radiation damage in the wall is attenuated"

the screening criterion [the transition temperature] during the anticipated life of the plant."

The "big-trouble" generating plant is the H. B. Robinson 2 reactor of Carolina Power and Light. Hanauer calculated that if nothing were done, it would reach the transition-temperature criterion in September of 1987. Turkey Point 3 and 4 in Florida get there in 1988; Calvert Cliffs 1 in Maryland gets there in 1989; and Fort Calhoun in Nebraska arrives in 1990. Rancho Seco, Maine Yankee, Oconee 2 in South Carolina, and Three Mile Island 1 arrive in the 1990s. Everything else is 21st century, Hanauer says.

Reactor manufacturers accepted those numbers without too much argument. "Their conclusions are more or less in line with ours," said Sero of Westinghouse. Sero says that Westinghouse thinks the NRC could set its transition-temperature numbers about 30 degrees lower, but he isn't arguing with the basic premises of the report.

Nuclear critics are. They center their fire on the vast number of assumptions that had to be made in the report because information about the probability of different events occurring and about the reliability of safety systems simply isn't available. Rep. Markey's reaction, for example, was that the risk-assessment technique was "like predicting the winner of the World Series after the first exhibition game."

There's also a lot that the utilities and manufacturers can do to lessen any possible danger, industry experts say. One easy step is to reshuffle the fuel elements in the reactor core, putting older fuel elements, which emit fewer neutrons, close to the vessel wall. "It's easy and cheap to reduce neutron flux by a factor of two," acknowledged Hanauer.

Critics say that repositioning the fuel elements isn't enough. They want American utilities to reduce neutron exposure even further by inserting dummy fuel elements next to the vessel wall. That's been done at two reactors in West Germany and one Russian-built reactor in Finland. But utilities are reluctant to take the reduction in generating capacity that dummy fuel elements bring.

There are many other steps that can be taken, Marston said. One is the marvelously simple measure of heating the emergency cooling water to reduce thermal shock. Keeping the emergency water supply at 120 degrees F rather than room temperature is cheap and effective, Marston says. Thermal shock can also be reduced by adding controls to throttle back the automatic-feedwater system, he notes.

Improved training for reactor operators is another industry option. The idea is to get them ready for all the problems that could lead to a significant transient, then avoid the sequences that end in serious trouble.

The last resort is annealing. The reactor would be shut down, all the fuel elements would be removed, and the vessel would be heated to 850 degrees F for a week. A study done by Westinghouse for the Electric Power Research Institute concluded that annealing would make the vessel walls young again. The process isn't cheap. One report cited costs of $60 million or more for a single reactor, including the price of the electricity that the plant did not generate during the treatment.

No one is thinking about annealing right now. Instead, utilities and manufacturers are making detailed studies of all the factors affecting the thermal-shock issue for individual plants. The NRC report has asked for such a plant-specific report at least three years before a reactor reaches its screening criterion for danger.

For the Robinson 2 reactor, the report would be due in 1984. Carolina Power and Light is hard at work, says

Thomas S. Elleman, who is in charge of nuclear safety. The vessel wall has been inspected, and no cracks were found. New training for reactor personnel is under way. The company is studying a proposal to heat the emergency water supply.

Neutron exposure has been reduced by putting the older fuel elements next to the reactor wall. How much extra time will the program buy? "It's premature to speculate about that," Elleman said.

There's no panic at the NRC, the manufacturers, or the utilities. The problem is well understood, Cheverton says, and the Oak Ridge analysis indicated that even if worse came to worst, a reactor vessel would not break wide open. "Even though the inner portion is brittle, the outer portion still is relatively tough because the radiation damage is attenuated through the wall," Cheverton said. "A crack might be driven through the inner part, but it tends to arrest at the outer part."

But that assessment could easily be wrong, says Pollard of the Union of Concerned Scientists. "There's no dispute that current emergency systems would not be able to cope with a fracture of the reactor vessel," he said. "For other problems, you can make a reasonable argument that you have some defense in depth. The defense-in-depth philosophy disappears when you talk about pressurized thermal shock."

The real problem, Pollard says, is that the nation's nuclear regulators and the manufacturers allowed a major construction program to roar ahead without considering the range of unknown dangers that lay before them.

"The Atomic Energy Commission went forward with all this undue optimism," complained Pollard, who resigned from his job as a regulator years ago in disgust. "Now we're in a position where nothing can be done to correct the mistakes without causing someone undue harm. I expected them to do the job back in the 1960s. Now everyone but the nuclear industry has to suffer."

"My perception is that the problem is well in hand," said Westinghouse's Sero. "We have significant research programs under way, we are putting significant money and engineering efforts into it, and we have a firm understanding that is going to improve, which will show that our predictions were very conservative." ◘

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FOR IMMEDIATE RELEASE
(Wednesday, July 24, 1985)

NRC ADOPTS FINAL RULE FOR FURTHER PROTECTION AGAINST PRESSURIZED THERMAL SHOCK EVENTS

The Nuclear Regulatory Commission has amended its regulations regarding required protection against pressurized thermal shock events in licensed pressurized water reactors.

Pressurized thermal shock events are those which result in sudden decreases in temperature in a reactor vessel while the pressure remains high, such as would be caused by a main steamline break. These events could lead to vessel cracking if the vessel were sufficiently embrittled due to neutron irradiation. A cracked vessel could, in turn, lead to a loss-of-coolant accident and possible melting of the nuclear fuel.

The temperature range in which a reactor vessel being cooled by a pressurized thermal shock event loses a significant amount of toughness and becomes more subject to possible cracking is characterized by a "reference temperature for nil ductility transition." Embrittlement due to neutron irradiation causes the "reference temperature for nil ductility transition" to increase to high values. This means that less severe, and therefore more frequent, cooling events will cool the vessel below the "reference temperature," where it becomes more brittle. The actual reference temperature present in a particular vessel at a given time depends on the specific material in the vessel wall and the amount of neutron irradiation that has been received by the vessel up until that time.

The amendments include a "reference temperature for nil ductility transition" screening criterion below which the risk from pressurized thermal shock events is considered acceptable. The risk above that level also might prove to be acceptable, but a demonstration would require plant-specific evaluations and, possibly, modifications to existing equipment, systems and procedures.

The screening criterion imposed by the NRC is a "reference temperature" of 270 degrees Fahrenheit for plate materials and axial welds or 300 degrees Fahrenheit for circumferential welds.

Under the amendments, all utilities will be required, within six months of the effective date of the amendments, to calculate the present and projected future "reference temperature" for their individual vessels.

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In cases where the value is expected to to exceed the screening criterion before expiration of the operating license, utilities will be required, within nine months of the effective date of the amendments, to submit a plan and schedule of implementation for a program to reduce neutron irradiation of the reactor vessel to a level that will assure that the screning criterion will not be exceeded before expiration of the operating license.

If a reasonably practicable program of neutron irradiation reduction does not assure that the screening criterion will not be exceeded before expiration of the operating license, a plant-specific analysis will have to be submitted to the NRC staff at least three years in advance of the estimated time the screening criterion would be reached.

The analysis must include a quantitative assessment of the risk from pressurized thermal shock events due to operation of that particular plant and identify protential event sequences that contribute significantly to that risk. It also must consider the expected frequency of such events and the probability of resulting reactor vessel failure and core melt.

In addition, the analysis must include a review of what modifications, if any, might be necessary in equipment, systems and procedures to reduce risk due to PTS events to an acceptable level.

The analysis also may justify continued operation at values above the "reference temperature" screening criterion on the basis of risk reduction resulting from any necessary modifications.

The amendments to Part 50 of the Commission's regulations become effective on July 23, 1985.

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(EDITORS: This information has also been release by the NRC in Washington, D.C.)

60°F/hr and 100°F/hr. The 20°F/hr curve would apply to cooldown rates up to 20°F/hr: the 60°F/hr curve would apply to rates from 20°F to 60°F/hr; the 100°F/hr curve would apply to rates from 60°F/hr to 100°F/hr.

The Unit No. 3 heatup and cooldown curves for up to 5 EFPY are given in Figures 10 and 11. Unit No. 3 curves covering 5 to 10 EFPY are given in Figures 12 and 13. Corresponding curves for Unit No. 4 are given in Figures 14 through 17.

(3) trend curves of increase in RT_{NDT} as a function of neutron fluence (E > 1 MeV). A summary of these values is as follows:

Unit No.	Operating Period*	RT_{NDT} at 1/4T	RT_{NDT} at 3/4T
3	5 EFPY	194°F	131°F
3	10 EFPY	236°F	159°F
4	5 EFPY	281°F	188°F
4	10 EFPY	342°F	230°F

* EFPY = Effective Full Power Year

2. Vessel Constants

The following input data were employed in this analysis:

Inner Radius, r_i	=	77.75 in.
Outer Radius, r_o	=	85.78 in.
Operating Pressure, P_o	=	2235 psig
Initial Temperature, T_o	=	70°F
Final Temperature, T_f	=	550°F
Effective Coolant Flow Rate, Q	=	97×10^6 lb_m/hr
Effective Flow Area, A	=	19.15 ft^2
Effective Hydraulic Diameter, D	=	11.9 in.

C. Heatup and Cooldown Limit Curves

Heatup curves were computed for a heatup rate of 100°F/hr. Since lower rates tend to raise the curve in the central region (see Figure 8), these curves apply to all heating rates up to 100°F/hr. Cooldown curves were computed for cooldown rates of 0°F/hr (steady state), 20°F/hr,