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AUTHOR:	Mr. Robert Leyse		
AFFILIATION:	ID		
ADDRESSEE:	Mrs. Kathleen Trever, ID Dept of Environ. Quality		
SUBJECT:	Tub replacement for main condenser at Columbia Generating Station		
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From: <Bobleyse@aol.com>
To: <kathleen.trever@deq.idaho.gov>
Date: Tue, Sep 19, 2006 8:17 PM
Subject: Tube replacement for main condenser at Columbia

Kathleen:

Five years ago we had e-mail exchanges regarding the Columbia Generating Station. You contacted the NRC and they correctly responded that Columbia was well aware of the situation at the River Bend BWR in Louisiana (fouling of fuel elements). Of course, as usual, the NRC (and Columbia) did not elaborate.

The other day I was crawling around GOOGLE and I stumbled across the following:

www.energy-northwest.com/downloads/Main%20Condenser.pdf

and

www.energy-northwest.com/downloads/Main%20Condenser%20Addendum%201.pdf

I do not believe that Columbia intended for these to hit the fan, but they are out there.

So, to finalize. INL is the center for Nuclear Power Technology in the USA. The INL experts, independent of EPRI, should look into the situations that are outlined in these two documents. My belief is that Columbia has postponed tube replacement in the main condenser for too long.

In the hands of experts the two documents will speak for themselves. So, please let me know what INL thinks about all this.

The Chairman, NRC should insure that NRC is aware of the two referenced documents and that they are placed into the PDR.

Bob

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CC: <Chairman@NRC.gov>

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From:	<Bobleyse@aol.com>
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Columbia Generating Station
Main Condenser
By W. Scott Oxenford, VP Technical Services

This document summarizes longstanding performance issues related to the design and operation of the Main Condenser at Columbia Generating Station and solutions to those challenges.

The following categories summarize the issues in introductory level detail:

1. System Components Overview
2. Condenser Leakage
3. Columbia's Condenser
4. Columbia Historical Actions
5. Can Columbia Eliminate Condenser Leakage by Eliminating Debris?
6. Industry Data and Experience
7. Solutions

Addendum 1 has been included to highlight costs associated with condenser leakage.

Section 1: System Components Overview

The Purpose of the Main Condenser

The main condenser is a key component in the closed-loop system that transfers energy from the reactor to the turbine, in support of creating electricity. The condenser's primary function is to take steam exhaust from the main turbine and return it to a liquid form. The liquid, called condensate, is highly purified water. The condensate is preheated and pumped back to the reactor pressure vessel where energy in the form of heat is added to convert the condensate back into steam.

See Figure 1 for a simplified diagram (page 9)

Condenser Configuration

The Columbia condenser has three main sections:

1) The steam space, into which the turbine exhaust and other steam sources discharge.
2) The cooling section, where steam passes over brass water pipes filled with cold circulating water, causing the steam to condense back into water (condensate).
3) The circulating water interface consisting of waterboxes, tubesheets, and thousands of tubes. Chemically treated Columbia River water is circulated through special brass tubes, removing heat and transferring it to the Cooling Towers.

Cooling Towers

The cooling towers provide a water source for the circulating water system and transfer heat to the environment. Evaporative losses are replaced with water from the Columbia River. By nature, the cooling towers act to concentrate debris and impurities. Acid and other chemicals are added to reduce secondary system fouling and corrosion.

It is paramount to prevent the chemical additives and raw water/organic materials from degrading reactor coolant quality.

Section 2: Condenser Leakage

What Happens During a Small Condenser Tube Leak?

Due to pressure differences, small amounts of chemically treated raw cooling water (circulating water) are transferred to the pure reactor grade water in the condensate system. This water is then run through filters, removing some of the introduced impurities. Impurities that get through the filters then go to the reactor vessel, where they begin concentrating. The concentration takes place as the pure water boils into steam and the impurities are left behind.

As condenser leakage increases, the filters become less and less effective at removing the impurities.

Limitations to the Columbia Design

Some Boiling Water Reactors (BWRs) were designed with, or subsequently added, additional filters in their condensate systems. Called deep bed demineralizers, they are located between the filters like those at Columbia and the reactor pressure vessel. The deep bed demineralizers enhance filtration and water quality prior to entering the reactor. They allow continued safe operation with much greater condenser leakage than is possible with Columbia's design. Additionally, the filters are effective at removing copper, which will be discussed later.

Results of a Small Condenser Leak

Even a small condenser leak has negative consequences for Columbia, including:

- Filters must be changed more frequently to keep the water as pure as possible. Changing filters twice as often (frequently required) increases the cost of the filter media (resin) and the associated disposal cost (radioactive waste that needs to be buried). Each of these operations and disposal maneuvers also impact labor costs and employee dose (radiation exposure).

- Once a leak is large enough to locate, the plant is reduced to approximately 60% power to pinpoint and repair the leakage. Pinpointing and repairing leakage from multiple, small locations, is especially difficult. Each repair entails unplanned

generation losses, employee exposure, personnel safety hazards, and increased labor costs.

See Figures 2A-B (pages 10-11)

- Water quality (chemistry) within the reactor degrades. This can:
  1) Result in unplanned power reductions or mandatory shutdowns due to exceeding chemistry limits.
  2) Increase activation of impurities, which increases radioactive contamination and exposure throughout the plant.
  3) Increase the susceptibility of the reactor vessel and internals to cracking, increasing the likelihood for costly repairs.
  4) Disturb the corrosion layer on the fuel and reactor internals. Impacting the fuel corrosion layer can lead to fuel damage. Fuel damage can result in plant de-rate, unplanned refueling outages, increased dose rates and employee exposure, and increased stack release rates to the environment.

Section 3: Columbia's Condenser

Admiralty Brass Material

Columbia's condenser tubes, like many original condensers, were fabricated from admiralty brass. Admiralty brass is made primarily of copper, with the second largest constituent being nickel. It was selected for its excellent heat transfer efficiency and inexpensive cost relative to other suitable materials.

Susceptibility to Mechanical Wear

Admiralty brass is more susceptible to damage than the other contemporary condenser materials like stainless steel and titanium. For example, plastic tie wraps have caused leaks in our condenser when they became lodged at the inlet end of condenser tubes and, moved by water flow, wore holes in the soft metal tubes. Titanium is approximately 6.5 times harder and stainless steel is about 3 times harder, making them less susceptible to debris induced damage.

Likewise, steam leakage from exhaust lines into the condenser has been known to wear through tubes, leading to rapid increases in condenser leakage and prompt shutdown of the plant to protect primary system chemistry.

Copper and Fuel

Even slow wear of the soft condenser tube material adds copper to the condensate. Columbia demineralizers are not designed for mechanical filtration, the best method for removal of copper. Based on that and the lack of deep bed demineralizers, Columbia is classified as a 'high copper plant'.

Copper's substantial negative impacts on Reactor fuel integrity were identified in the early days of Boiling Water Reactors. A phenomena, known as Crud Induced Localized

Corrosion (CILC), is caused by copper entering the reactor, attaching itself to the fuel corrosion layer, and causing localized corrosion and high temperature areas on the fuel cladding. The eventual outcome is often loss of clad integrity and long axial splits of the clad. That allows fission products to spread throughout the plant and ultimately cause increased release rates to the environment. CILC has rendered large quantities of fuel unusable, costing tens of millions of dollars and extended reduced power operation at some units.

See Figure 3 (page 12)

The industry has substantially lessened, but not eliminated, CILC failures by removing copper from their condenser materials or adding deep bed demineralizers. Columbia has done neither, leaving us susceptible to CILC fuel failures. Columbia has carefully selected fuel cladding to minimize the risk of CILC failure. However, the only real way to rule this failure mechanism out is to remove the source of copper completely.

In addition to fuel impacts, copper is also implicated in the trapping of cobalt in the corrosion layers on all reactor internals. This increases overall plant radiation levels and dose to our employees.

Early Condenser Damage

Poor chemistry control in the early years of Columbia's operations caused corrosion of the condenser tubes. One result is a phenomena, called dezincification, which caused pits in the condenser tube metal. The pits remain and provide initiation sites for localized corrosion and subsequent tube leaks/failures. Based on this, Columbia cleans and "eddy current tests" one-third of our condenser system per outage. With our transition to two-year cycles, Columbia needs to start conducting eddy current tests of all the condenser tubes each outage, starting with R18 in 2007. The $700k per outage testing cost could be substantially reduced with improved condenser material condition.

Section 4: Columbia Historical Actions

Columbia management conducted a condenser replacement study in 1996. No action was taken on the study results based on unfavorable payback expectations and extended outage time for condenser tube replacement. A key factor at the time was the uncertainty of plant license extension.

Our concerns resurfaced in 1999 following fuel failures at the River Bend plant (admiralty brass condenser with deep bed demineralizers). We closely tracked the River Bend cause analysis. River Bend fuel corrosion had high copper levels, but the failures were attributed to high iron levels in their corrosion layer. Based on Columbia being a low iron plant, no action was taken.

See Figure 4 (page 13)

During 2001, Columbia found that some of its fuel had thicker than expected oxide layers. A root cause team, with industry expertise, studied the previous operating cycle and fuel scrapings. The fuel had higher than normal levels of copper and iron deposits. Concerns over probable fuel damage were high. Spallation (similar to concrete spallation where material falls off) was identified on Columbia fuel.

See Figure 5A, B, C (pages 14-16)

The root cause was determined to be poor demineralizer performance, coinciding with a chemical intrusion due to condenser system leakage. Had the condenser not leaked this challenge to the fuel would not have occurred.

In 2003, another copper reduction study was initiated that included consideration for deep bed demineralizers or removal of the admiralty brass. The recommended solution was not completed due to external cost pressures.

Columbia's management has thoroughly reviewed options for managing ongoing condenser challenges. On each occasion, continued operating risks were accepted instead of taking action, primarily to avoid costs and extended outage length.

In addition to these studies:

- Columbia has increased the size of our demineralizers to improve filtering efficiency.
- Determined the suction screen on the circulating water system was not properly seated, allowing some debris to pass. Columbia has corrected this and implemented a long-term fix.
- Columbia rebuilt three cooling towers, upgrading the plastic fill and lattice, while removing all plastic tie wraps at $2M per tower. Three towers remain original.
- Columbia has improved our foreign material controls to reduce debris getting into circulating water and subsequently the main condenser.
- Columbia has improved waterbox drainage to allow faster and more complete draining for repairs.
- Columbia staff is looking at screen options in the upcoming outage to further reduce debris entry into the main condenser.

<u>Section 5: Can Columbia Eliminate Condenser Leakage by Eliminating Debris?</u>

In any raw water system, debris elimination is a challenge that plant designers are faced with. Columbia is blessed with a relatively clean water source in the Columbia River. The Tower Make-up System takes water from the middle of the river through screens. Columbia also has screens at the intake to the Circulating Water Pump Pits. These screens are designed to be small enough to prevent plastic tie wraps and larger debris from passing. Despite this, items pass through the screens or are in the system from

historical operation. Additionally, the screens must be manually raised for cleaning with the plant in operation which allows debris entry.

Cooling towers, due to their design purpose of transferring heat to the environment, are open and susceptible to items being blown in, dropped in from animals, and dropped in during work under adverse conditions. Additionally, the extreme weather variations, water flows, chemical additives, and ice build-up cause corrosion and damage that create debris. Any raw water screen system can reduce debris intrusion, but none appear to be 100% effective.

See Figures 6A-D (pages 17-20)

Finally, in 2003, INPO shared a Significant Experience Report on debris intrusion. The document shares operating experience with screens becoming plugged and causing loss of pump suction. This is an issue Columbia has experienced from algae build-up on plant restarts. Reduction in screen opening size increases the likelihood of plugging.

In May of 2004, a root cause analysis was performed to prevent debris related condenser leaks. Remaining actions from that study are planned for implementation in the upcoming outage. Columbia's actions to date have reduced the quantity of debris in the condenser, and should improve more with an improved screen system. However, debris intrusion will always be an issue to some extent.

It should be noted that the root cause <u>'does not address tube leaks caused by steam impingement or long term flow induced erosion or other service related tube damage such as dezincification and stress corrosion cracking'</u>. These failure modes were specifically excluded for the purpose of focusing on debris-related leaks, which caused the condenser leak triggering the root cause analysis.

Section 6: Relevant Industry Data

<u>Current Main Condenser Material</u>
Of the 34 US BWRs:
16 have stainless steel condensers.
10 have titanium condensers.
4 have a combination of admiralty brass with stainless steel or titanium. These sites use the less damage-susceptible materials in the highest risk areas.
Only 4 have admiralty brass condensers, including Columbia.

Our data shows at least 13 of the BWRs have re-tubed their condensers. Nearly all had admiralty brass and went to a different material. Most occurred in the 1980's and 1990's.

See Figure 7 (pages 21-22)

Current Plants with Deep Bed Demineralizers
Of the 34 US BWRs, 20 utilize deep bed demineralizers.

Of the 8 US BWRs containing some admiralty brass in their condenser, only two operate without deep bed demineralizers to address copper. They are Columbia and Vermont Yankee. Vermont Yankee went commercial in 1972. It is a small 593 MWe BWR recently bought by Entergy. Vermont Yankee is planning condenser tube replacement as part of license renewal.

Two of the US BWRs with a combination of admiralty brass condensers and deep bed demineralizers are Limerick Units 1 and 2. Following major CILC related fuel damage on Unit 1, Limerick added deep bed demineralizers. This option was selected over re-tube because it was factored into the original design, with available space in their Turbine Building.

From this section, the case for change, based on copper alone, is strong. We are one of only two operating BWRs that have admiralty brass condensers without deep bed demineralizers. The other BWR, Vermont Yankee, contains 8% stainless steel tubes.

Utilities invested in their facilities to reduce risk. At this point we do not know if their investments passed a business case payback analysis or if action was taken to eliminate the large downside risk, regardless of payback.

Political Landscape
Over the past several years, top focus areas of Chief Nuclear Officers have been Security, Fuel Reliability, and Materials Degradation. In the area of materials degradation, the industry established a program called BWR Vessel Internals Protection (BWRVIP) in 1994 so we could self-regulate, rather than cause the NRC to regulate us. The program provides research, inspection requirements, program requirements and independent audits to ensure the industry is protecting reactor pressure vessels and internals. Failure to protect these important components can have downside risks not only to individual stations, but the nuclear industry as a whole. We are currently failing to meet the BWRVIP guidance on copper in the reactor coolant, which provides a spotlight on Columbia due to having one of the more significant program deviations. Peer pressure to eliminate long-term deviations is growing.

Section 7: Solutions:

Deep bed demineralizers alone are not a preferred solution. They will reduce copper and impurities in the reactor coolant, but condenser leakage will continue to be a chronic problem and copper impurities will remain at a lesser amount. Unplanned downpowers and radiation exposure for condenser repairs will continue, but less frequently. Resin usage and radioactive waste will increase due to the large size of the

deep bed demineralizers. We also anticipate increased Security staffing due to an additional building to house the deep bed system.

On April 21, 2006 we entered into an agreement with Sargent & Lundy to perform a Feasibility Study on the main condenser. They recently did similar work for four Exelon BWRs and the Fort Calhoun Station. This will entail a comprehensive analysis of Columbia's history and that of the industry, resulting in recommendations to ensure long-term reliability of the main condenser. The study will be complete prior to the FY08 budgeting cycle. Engineering, design, and procurement are expected to start in FY08, with installation of some or all of the modification in R19 (FY09).

Condenser material replacement is clearly the preferred solution to eliminate leaks and copper sources, ensuring long-term reliability of Columbia's fuel, reactor vessel and internals.

For maximum protection and defensive strategy, installation of deep bed demineralizers in conjunction with condenser tube replacement is another solution. This is not currently under consideration. However, as the industry gains operating experience in fuels and materials degradation, the Columbia staff will stay abreast and take action as appropriate.

FIGURE 1
Circulating Water System

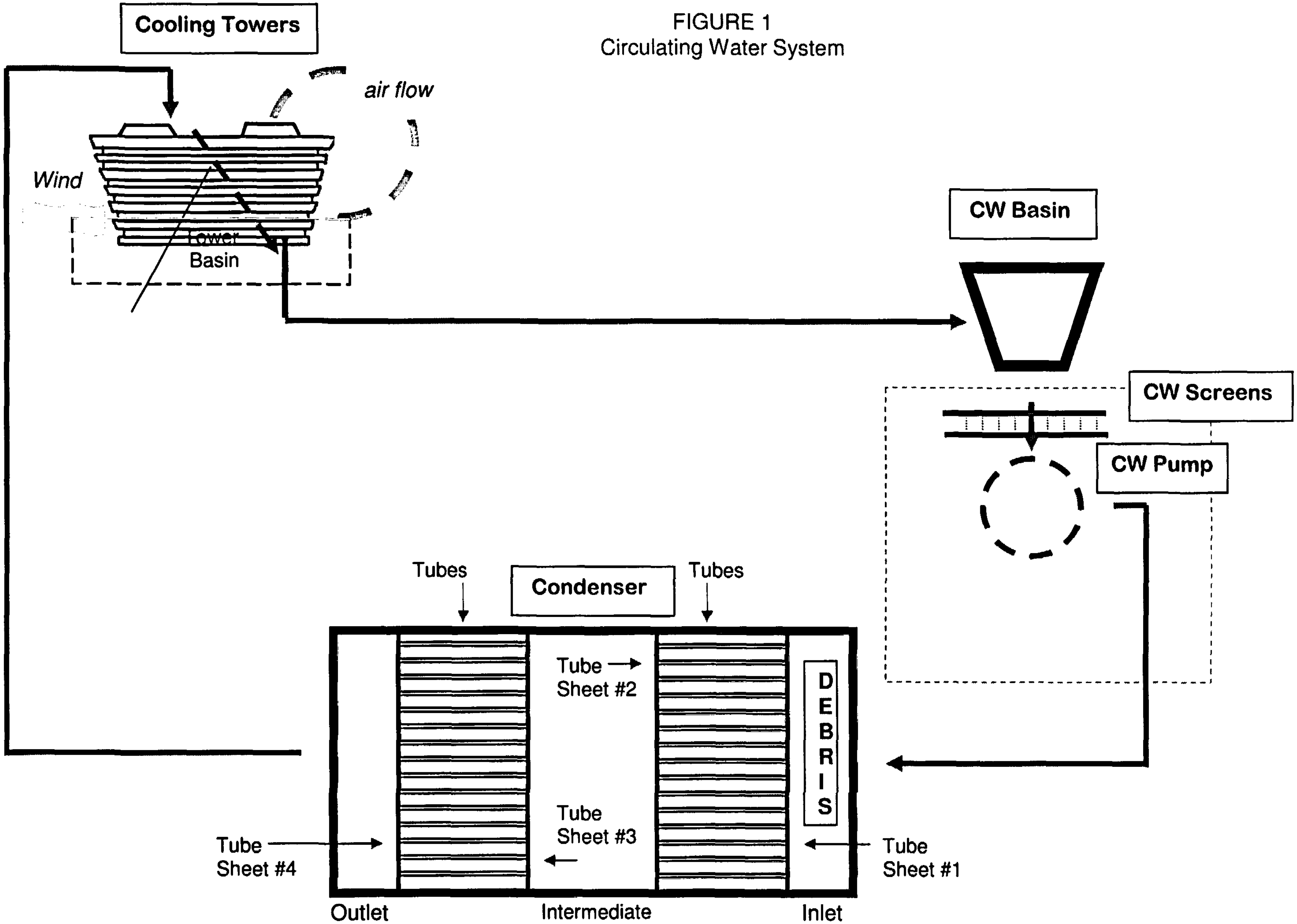

FIGURE 2A, Main Condenser Waterbox

Entry into the condenser waterboxes at power is a challenge to personnel safety. Single isolation valves (some eight feet in diameter) provide worker protection from system pressure. Entry is through small manways as shown in the picture.

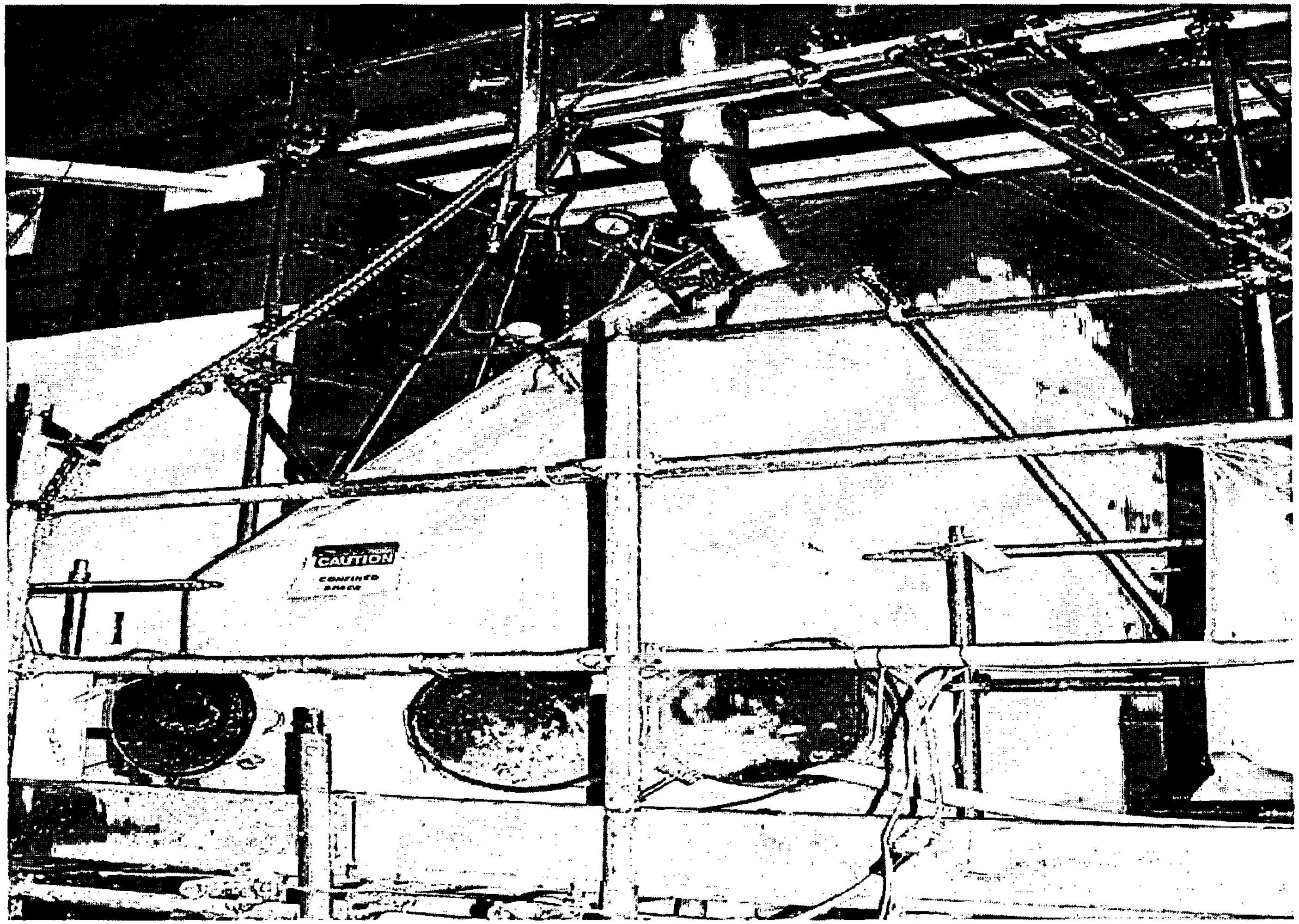

FIGURE 2B, Main Condenser Waterbox
This shows a worker inside the condenser waterbox.

FIGURE 3, Fuel that has undergone CILC related failures.

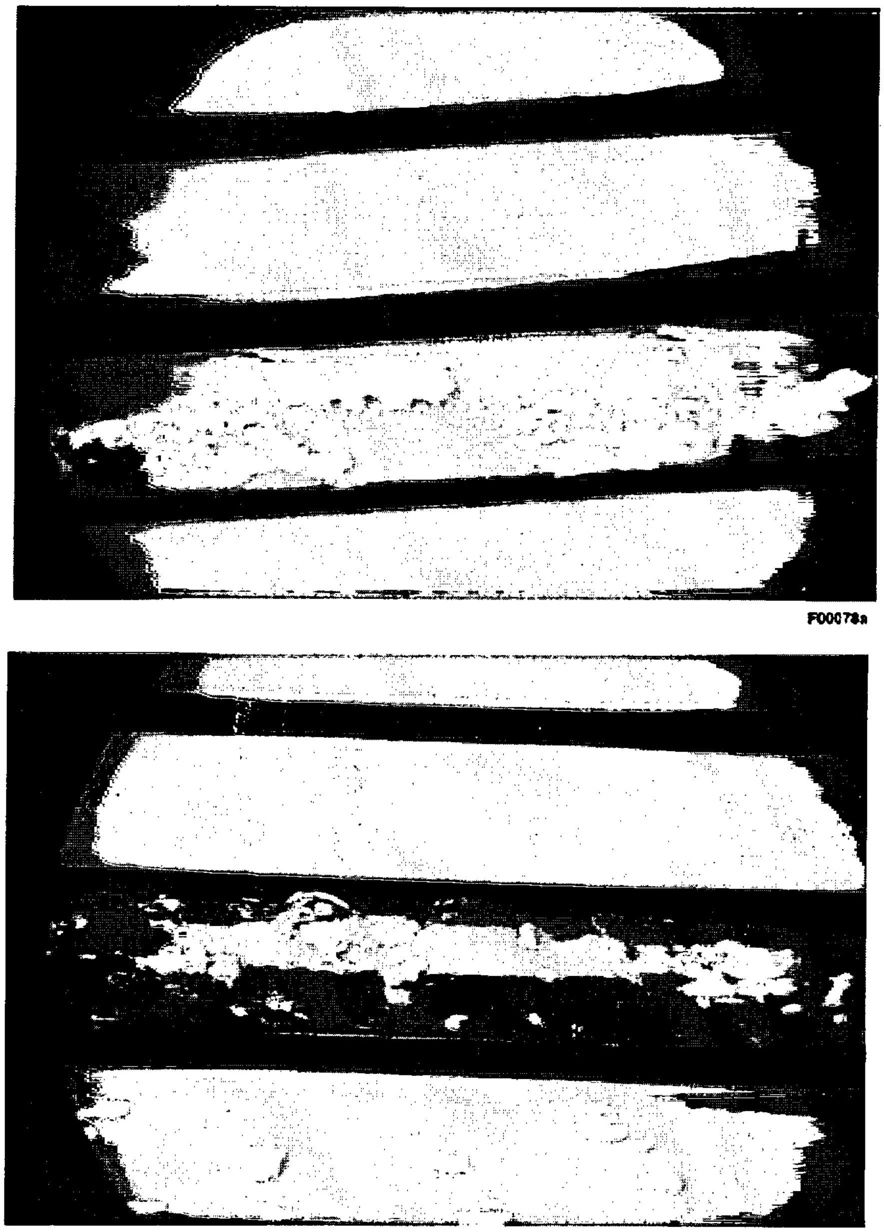

FIGURE 4, Failed fuel due to crud and accelerated corrosion.
This fuel was exposed to anomalous primary coolant chemistry, resulting in a heavy oxide layer and accelerated corrosion in 1999. It was fresh fuel.

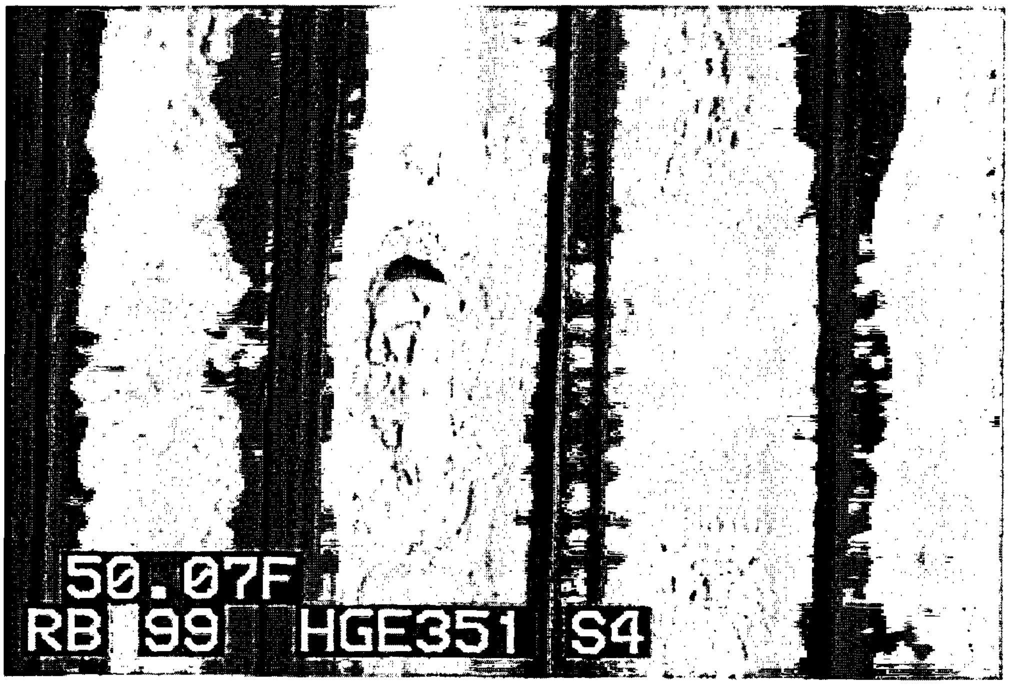

FIGURE 5A, One Cycle Fuel in expected condition.
The middle fuel rod has been brushed to remove the oxide layer.

CGS 1-Cycle Bundle (Before Chronic Condenser Leak)

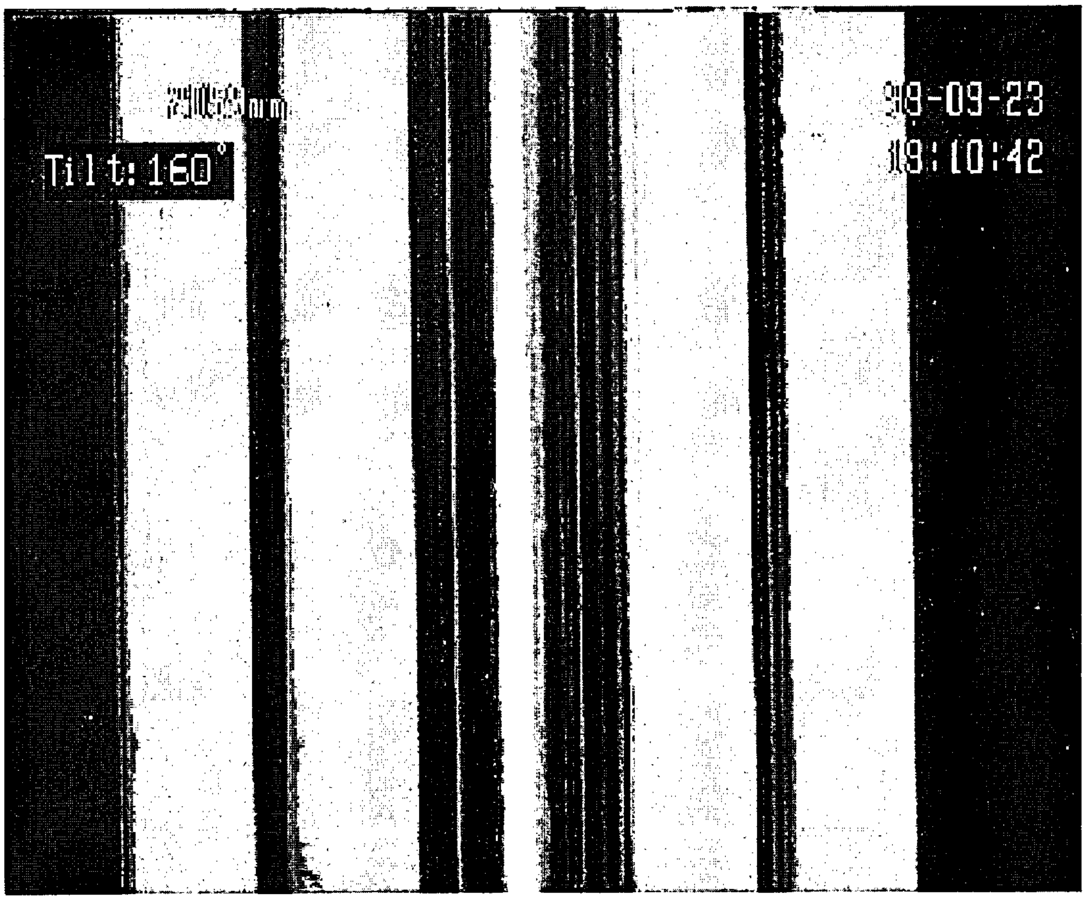

FIGURE 5B, One cycle fuel with it's oxide layer impacted by chemical contamination. Nodule formation has begun.

CGS 1-Cycle Bundle (After Chronic Condenser Leak)

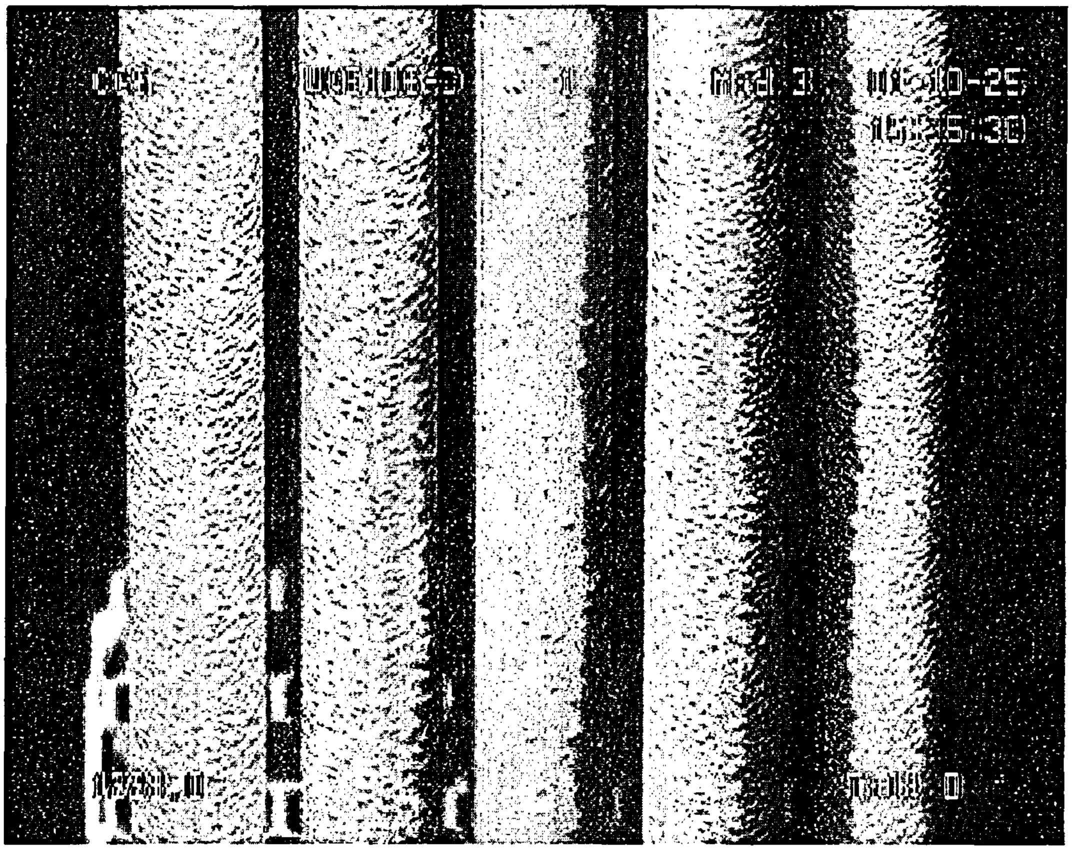

FIGURE 5C, Fuel that has been in the reactor for four cycles, following chemical contamination in the last cycle. Nodule formation and spallation is evident.

CGS 4-Cycle Bundle (After Chronic Condenser Leak)

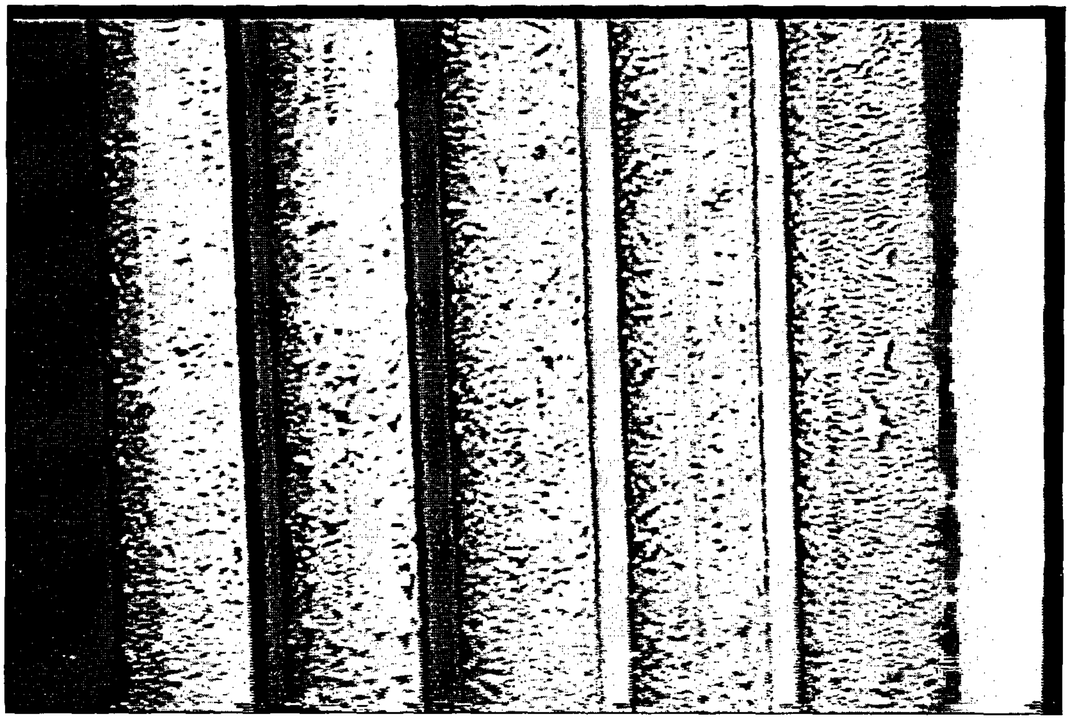

FIGURE 6A, Cooling Tower

As illustrated, the cooling towers have many openings to the environment that allow debris entry.

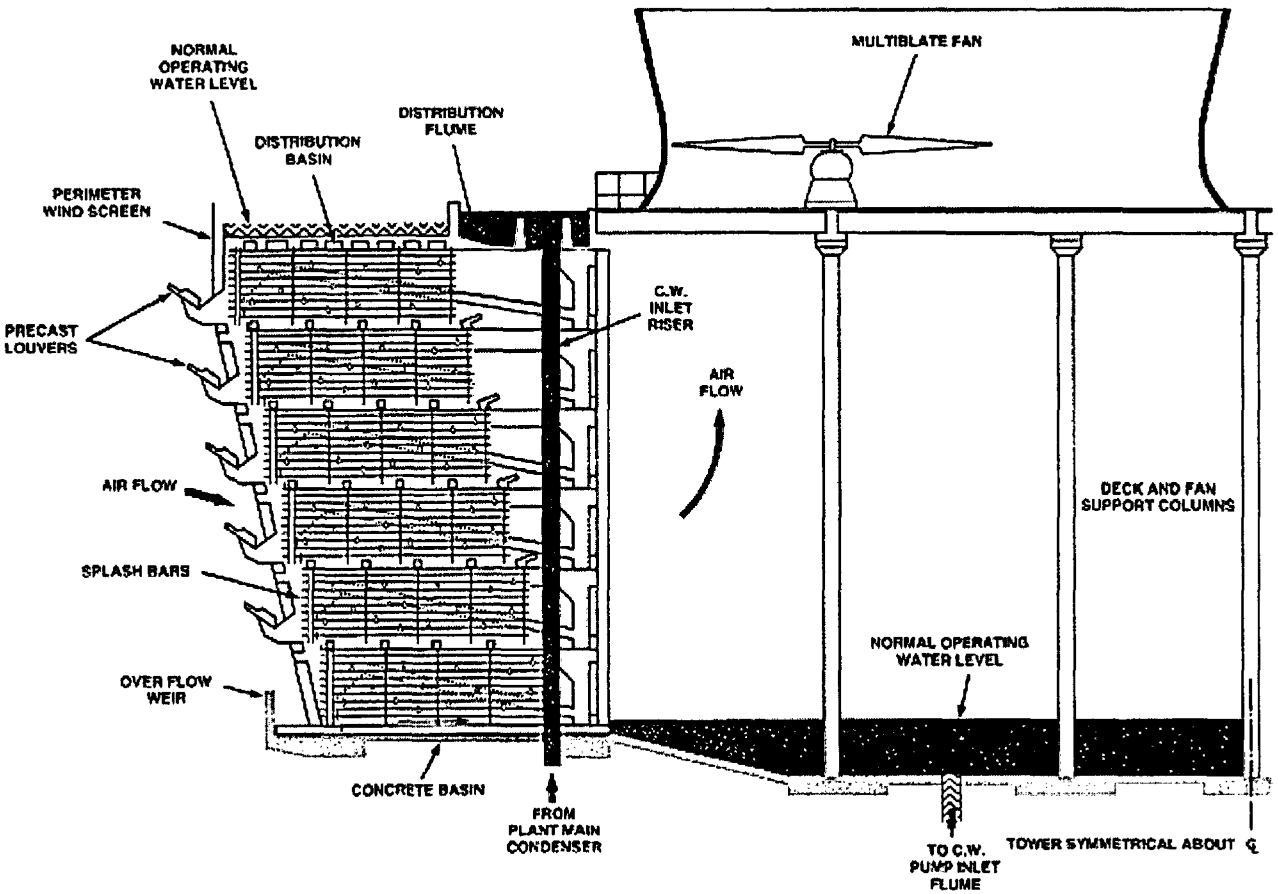

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FIGURE 4. COOLING TOWER CROSS SECTION

FIGURE 6B, Cooling Tower.
Large fans and vertical louvers allow debris entry pathways.

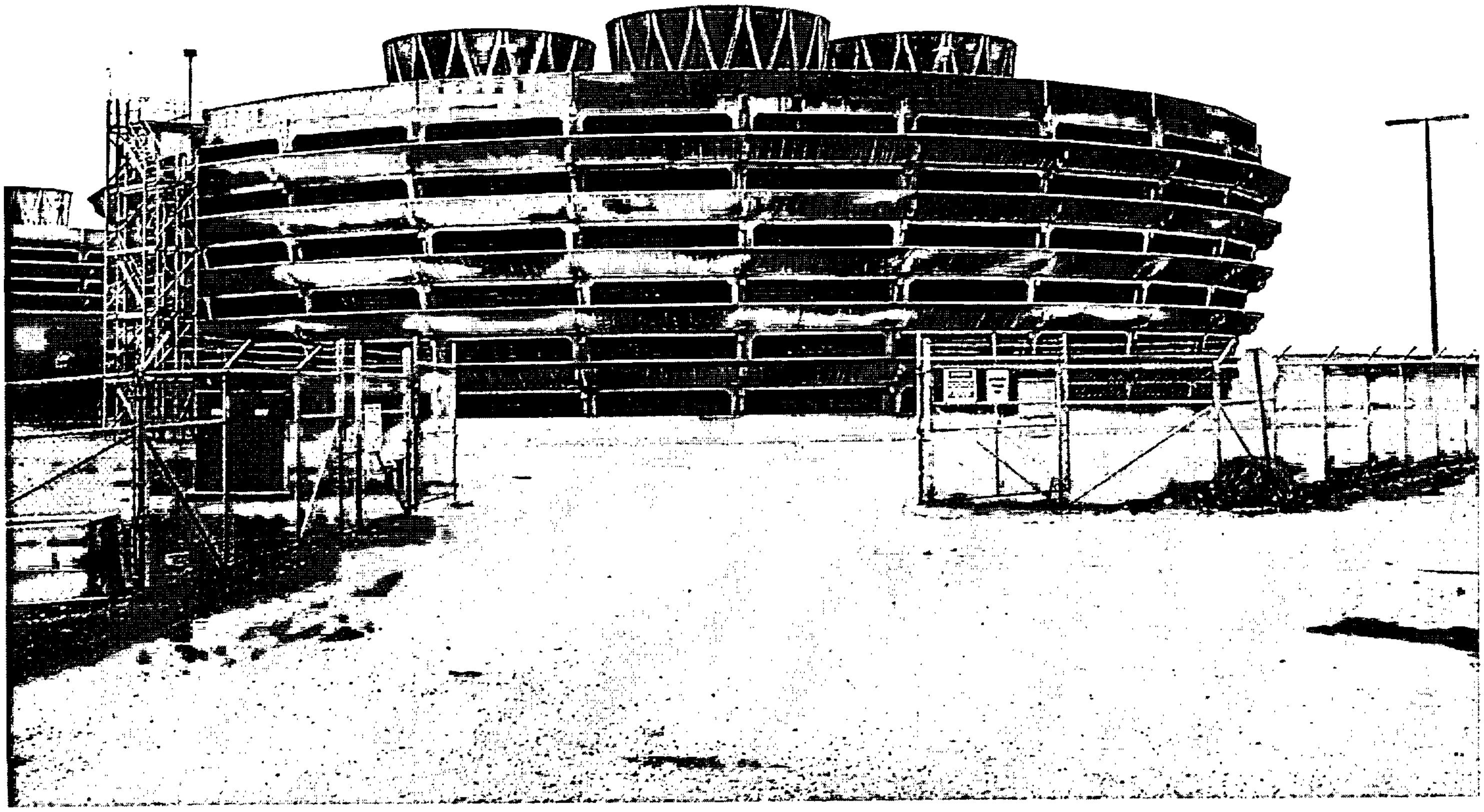


FIGURE 6C, Cooling Tower
Inside a drained Cooling Tower. Workers are careful to remove debris prior to returning it to service.

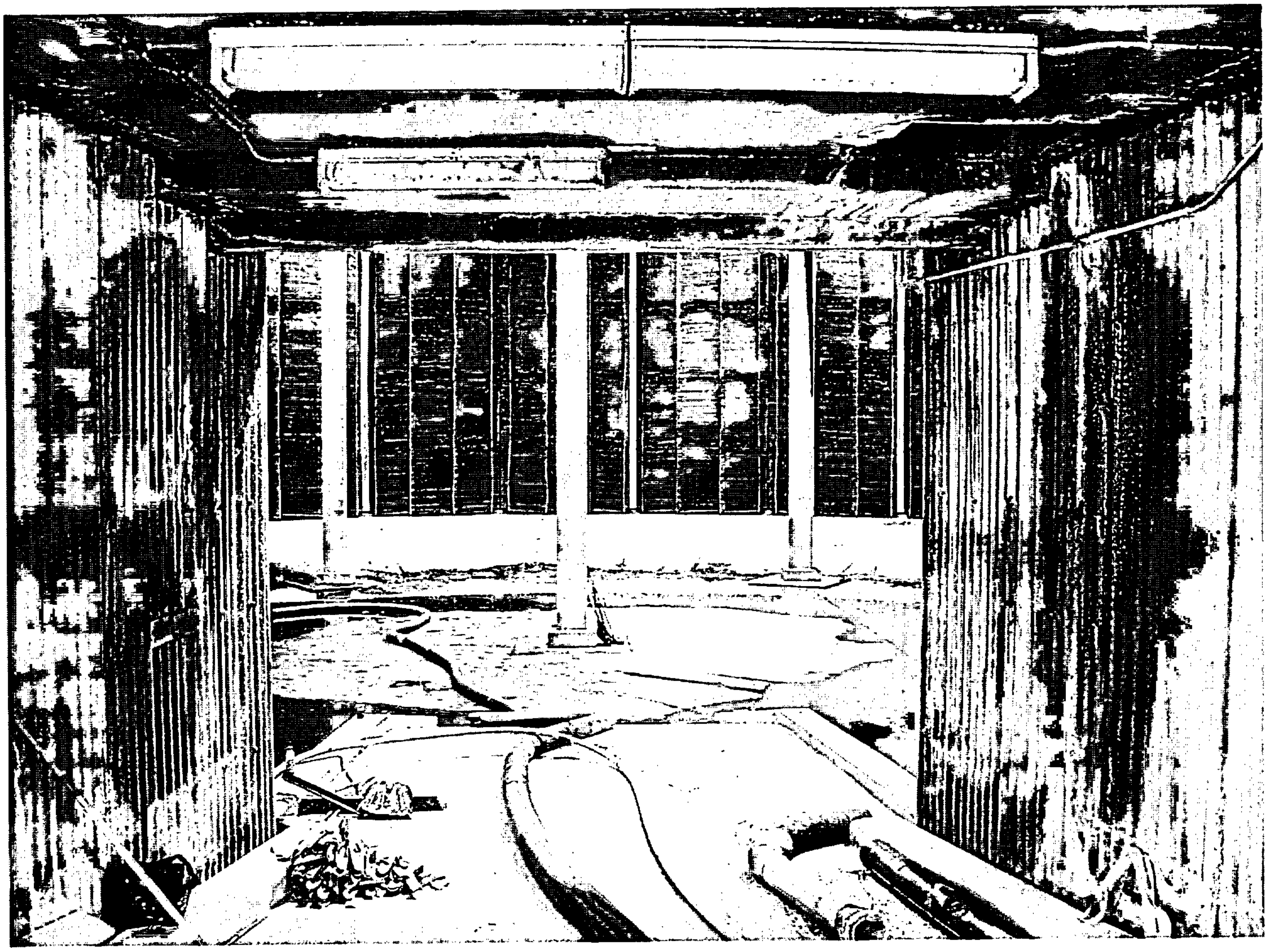


FIGURE 6D, Cooling Tower.
This drained Cooling Tower demonstrates how open to the environment they are. When in service, water fills these passages and falls to the basin below.

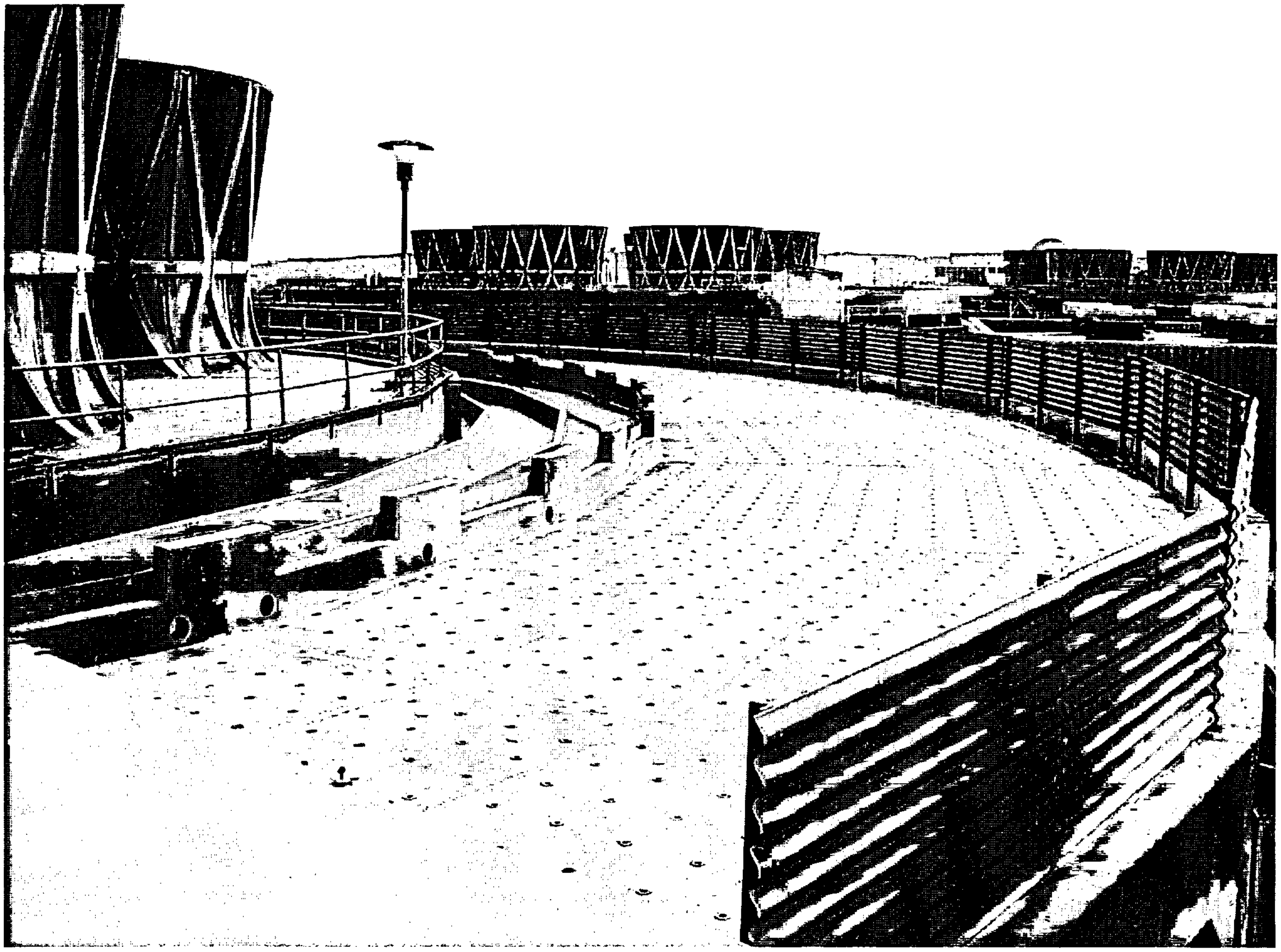


FIGURE 7, FERMI Condenser Replacement Article

INDUSTRY NOTES
PROCESS/MANUFACTURING/UTILITIES

Steam generation

Preplanning, analysis key to condenser retubing

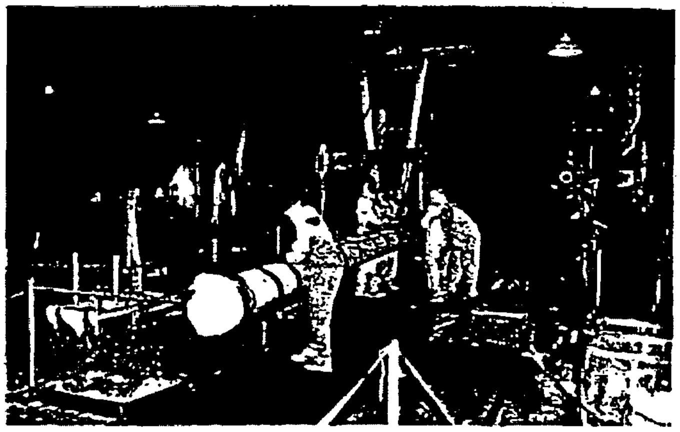
Degradation of condensers and the potential for forced outages or plant load reductions demand that utilities continually evaluate the possible need for condenser upgrading. A particular problem at nuclear powerplants has been high copper levels in the feedwater system, which has been tied to steam-generator corrosion in pressurized-water-reactor (PWR) plants and fuel-assembly corrosion in boiling-water-reactor (BWR) plants. Experience shows that radioactive contamination, increased personnel exposure to radiation, and significant loss of plant availability can result.

Fermi Unit 2, a BWR plant of Detroit Edison Co, is located on Lake Erie, a freshwater body of relatively good quality. The plant has a closed circulating-water system (CCWS) that relies on the lake for makeup. The CCWS comprises a pond, five circulating-water pumps, an Admiralty-brass-tubed, single-pass condenser, and two natural-draft cooling towers. General utility experience indicates a 12-15-yr expected condenser life for this material/system combination, limited primarily by erosion resulting from solids in the system.

Of 25 US and foreign BWR plants having condensers with Admiralty brass tubing, 17 have experienced crud-induced localized corrosion (CILC) of fuel-element cladding—in some cases resulting in fuel leaks and system contamination. Feedwater copper levels exceeding 0.2 ppb have been identified as a significant contributor. Problem condensers have been or will be replaced with stainless steel in three of the afflicted plants, and with titanium in 14.

While use of filter/demineralizers to control feedwater-copper buildup is one preventive approach, Leonard C Fron, the utility's condenser project manager, notes that limiting copper to levels down to 0.2 ppb adversely affects demineralizer run times and increases requirements for radwaste processing and waste disposal/storage. Removal of the source of copper provided the best long-term solution.

A decision was made to retube the condenser in December 1989, and the modification was targeted for the refueling outage (RF02) scheduled for March 1991. A formal project organization was set up in January 1990 to study, detail, and implement the modification, the staff functioning as a completely self-reliant entity both before and during the outage. In addition to Fron, key staff members were John Honkala, condenser project engineer, and John O'Donnell, condenser field engineer.



Radioactive contamination on tube surfaces and in condenser areas demanded special precautions for personnel protection

With the loss of generating capacity a key concern, the first order of business focused on the length of the outage. In the past, retubing of BWR plants of similar size and condenser-tube number has required from 75 to 110 days—less for condensers with significantly fewer tubes or for partial condenser-tube replacements. The selected outage provided a 65-day window for the project. This required an aggressive construction schedule and intensive, detailed preplanning.

Using previous historical data and input from Fermi 2, a utility consultant developed a construction schedule allowing 75 days from entry into waterboxes to completion of the concluding circulating-water test. Allowing for pre-outage work, use of separate stand-alone facilities, and sharp focusing of the job to minimize interferences from other outage activities, the project team shortened the schedule to 65 days. Ambitious as it may have seemed, this requirement was incorporated into the project specification, so bidders were prepared to present detailed 65-day schedules at the pre-bid meeting.

In accordance with utility policy for major contracts, the team established a fixed-price contract for retubing the condenser and developed a detailed specification, the heart of the contract. This did not preclude the requirement of prices for specific activities, manpower loading, a milestone schedule, and a detailed activity schedule. A detailed reference bid, moreover, was prepared to provide a basis for excluding low bids from contractors with marginal experience.

This strategy resulted in two very good proposals, and the award decision was based primarily on the contractor's management team and its experience in working together on similar projects. Success of the approach is measured by the fact that the project was completed ahead of schedule with a quality product and only 3% in additions to the original contract price.

Such an achievement, clearly, could not have been accomplished without a thorough analysis of the problems involved, evaluation of the available options and associated limitations, a detailed and realistic project schedule, and complete agreement on job-specific activities—all predicated on creation of a close-knit team with a unified approach.

This was accomplished over a period of nine months starting in July 1990, when the contract was awarded to United Engineers & Constructors/Catalytic, Philadelphia, Pa, and organizational interfacing commenced. Beginning in September, the general contractor and its subcontractors—Heat Exchanger Systems Inc, Boston, Mass, and Cannon-Sline, Philadelphia, Pa—worked closely with the project team to prepare a detailed schedule, locate providers of goods and services, and conduct the necessary analyses related to tubesheet stability, tube/tubesheet-joint strength, and protective-coating evaluations. So close and smooth were the interactions among involved personnel during this period that, by December 1990, they

were no longer identified by their individual organizations but as the Condenser Project Team.

Project elements. The primary considerations of the project were selection of the tube material and the replacement method. The replacement material would have to equal the plant's performance experience with Admiralty brass: operation close to design rating with fewer than 1% of the tubes plugged and fewer than 1% with 50% wall thinning. Other materials-related concerns were susceptibility to corrosion, erosion, and fouling of the internal surface.

Non-copper-based materials evaluated included Types 304 and 316 (austenitic), Type AL6XN ("super" austenitic), Type 439 (ferritic) and Sea-Cure ("super" ferritic) stainless steels, and titanium. The austenitic steels were not considered suitable because of the need for water-side layup procedures. Type 439 was eliminated because of susceptibility to pitting and crevice corrosion. Although the costs of the "super" stainless steels and titanium were comparable, titanium was selected because it has never failed from corrosion in powerplant condenser service. Its use for tube replacement in 14 BWR condensers, moreover, has been successful.

Replacement alternatives were rebundling, retubing only, and retubing with new tubesheets. Replacement of tubes as groups (bundles)—done with great success at several Scandinavian nuclear plants—was not possible at Fermi 2 because of the plant layout and interferences. This required hand removal of tubes, negating schedule advantages offered by modular replacement.

Despite galvanic incompatibility, it was decided to retain the existing carbon steel tubesheets, primarily because the condenser has center outlet waterboxes, which would have had to be dismantled to install titanium outlet tubesheets. The inlet tubesheets could have been replaced by removing the inlet waterboxes and cutting the tubesheet-to-condenser-shell weld. But this would have had to be replaced by a mechanical joint, introducing a potential for leakage.

Analysis of tubesheet and tube-joint loads indicated no significant change would result from retubing with titanium. Joint-strength tests were conducted to determine the acceptable tube-rolling torque under the allowable 1340-1590-lb forces expected at 55 psig, the design pressure of the circ-water system. Five 88-hole mockup tubesheets were made for pullout tests, two of them epoxy-coated to replicate the intended retubed-condenser tubesheet end-product. About 10% of the titanium tubes tested were coated with Loctite prior to rolling. Test results dictated rolling torques of 10.5 and 11 ft-lb at the inlet and outlet, respectively. Based on the worst-case pullout forces, these torque values produced a tube-to-tubesheet joint with a safety factor of two.

Additional analyses were related to condenser uplift, cathodic protection, tube vibration, and effects on circulating-water flow. Structural stability was a factor because the full complement of 22-BWG titanium tubes would be over one-million pounds lighter than their predecessors. Analysis showed that resulting uplift loads could be accommodated by the existing foundations, anchorage, and structure. Tests to determine the need for cathodic protection because of metal dissimilarities concluded that the tubesheet could be protected from galvanic corrosion by coating alone, without use of a sacrificial anode or impressed-current cathodic protection.

Corrosion calculations based on measurements made on test assemblies placed in the circulating-water pump house indicated expected corrosion rates below 10 mils/yr. Because other approaches were cost-prohibitive, and assuming no coating imperfections or failures, it was decided that a thick film coating with high impact resistance and excellent flexure, cathodic-disbondment, and dielectric-strength properties would provide adequate tubesheet protection.

Tube-vibration analysis indicated that the unsupported span length of the thinner-walled titanium tubes would have to be reduced to prevent vibration-induced failures. This dictated the need for staking the tubes, confirming the experience at other plants. Tubes in the air-cooler sections were not included because of the far lower velocities that they would be subjected to and the amount of work involved in installing stakes in these shrouded sections.

Type 304 stainless was chosen over other possible staking materials for its smooth surface finish, corrosion resistance, and ease of installation. A dimpled stake design was selected because it offered a locking capability. The pattern developed for full bundle staking required about 36,000 stakes of varying length.

Analysis of circulating-water flow indicated little impact on tube cleanliness, condenser pressure, or net generation would result from the reduced tube velocities in a titanium-tube condenser—from 7.05 ft/sec to 6.53 ft/sec with five pumps operating, from 6.28 to 5.80 ft/sec with four pumps. Velocities were judged adequate to maintain tube cleanliness factor at an estimated 90%. No appreciable increase in net generation would occur with five pumps until the circulating-water inlet temperature reaches 75F or higher.

Remaining uncertainties had to do with the condition of circulating-water valves, inlet and outlet tubesheets, condenser steam side, and support plates. Possible concerns included valve leakage, support-plate bowing, and microbiologically influenced corrosion (MIC) of tubesheets. The valves were cleaned, inspected, and adjusted for seating during several forced outages. Tubesheets were also inspected and special tube-work tooling determined. Steam-side condition was established and damaged components were fabricated before the start of RF02. The presence of rust nodules indicated areas of MIC.

Selection of the tubesheet coating required extensive research into the need for surface preparation before application of the coating. This was dictated by reports indicating premature coating failures were likely in MIC-affected areas if corrosion and bacterial colonies were not removed before the coating was applied. Possible solutions, ranging from ozonation to arrangement of steam chambers and flushing of tubesheet surfaces with potable water, appeared cost- and labor-intensive; limited documentation was available to provide bacteria counts before and after treatment to verify the effectiveness of efforts at eradication.

Accordingly, a treatment process was developed that would not impact the schedule nor be toxic to personnel or the environment. It involved hydroblasting, spraying with hydrogen peroxide, sandblasting, and washing with methylethyl ketoxime (MEK). A mockup tubesheet was prepared, Admiralty brass tubes were rolled in, and the assembly was immersed in circulating water on the pump suction side for six weeks, allowing buildup of a slime and corrosion layer similar to that developed on the condenser tubesheets. Examination of the assembly before treatment revealed the presence of corrosive-acid-producing bacteria.

The examination was repeated after each step of the eradication procedure. The end result was that 94% to 99% of the bacteria population was killed by hydroblasting, and another 2% by the peroxide wash. Following the MEK wash, total kill was 97% to 99%. This analysis enabled the elimination of MEK from the procedure. Before implementing the procedure during the outage, water samples were taken from MIC-affected areas for baseline data. Comparison to samples taken after hydroblasting—allowing time for bacterial growth—showed a 75.2% reduction in the bacterial colony count; the reduction achieved by hydroblasting followed by peroxide spraying was 97.8%.

The balance of the detailed pre-outage planning and activities called for by the retubing specification proceded on or ahead of schedule. As a result, the 60,000-tube condenser was retubed, coated, and tested in a period of 62.5 days with near-flawless workmanship. The work was completed 2.5 days ahead of schedule and 20% under the budgeted cost—all the more notable for having been achieved despite complicating conditions: contaminated tubesheets, radioactive tubing, and the use of special clothing to protect personnel from contamination at the waterbox faces (see photo). **Shel Strauss**

Columbia Generating Station
Main Condenser, Addendum 1

W. Scott Oxenford, VP Technical Services

This addendum augments the Columbia Generating Station Main Condenser white paper, providing a summary of economic impacts of condenser leakage.

The analysis is organized in two parts for clarity. The first provides an average cost per event or month. The second provides a cost breakdown over the current operating cycle, from June 2005 through May 2006.

Historical Perspective

Columbia has suffered eleven shutdowns and nine reduced power evolutions to address main condenser leakage since it began operation in 1984. The number of events speaks to the chronic nature of this costly operational challenge.

Condenser related shutdowns and down-powers would have been even more frequent if it were not for repeated plant shutdowns, extended economic dispatch periods due to river flows, and annual operating cycles. Each of those operational attributes provided opportunities to perform condenser repairs reducing the potential for even more condenser related shutdowns.

Direct Cost Impact

Chemistry Control

Columbia's condensate filter demineralizers are changed more frequently to minimize impurities reaching the reactor pressure vessel. The demineralizers are coated with a powdered resin. The costs of increased resin use, shipment, and disposal of the associated radioactive waste is included. Additionally, the circulating water system is operated to reduce the level of impurity concentration, requiring increased chemical treatment.

$124,000/month
Average chemistry-related cost for each month Columbia operates with a condenser leak.

$1,030,000
Aggregate chemistry-related cost for this operating cycle (June 05 to May 06).

Tube Plugging Evolution

A tube plugging evolution is performed at reduced power and takes about three days. Detailed planning, oversight, and around the clock coverage limit lost generation. The actual tube plugging activity involves isolating a section of the

condenser, draining it with multiple pumps, cleaning the tubes, identifying the leak(s) and inserting plugs. The evolution involves Columbia staff level of effort, overtime, and the use of contractors.

$350,000/evolution
Average incremental direct costs associated with one tube plugging evolution.

$1,400,000
Aggregate cost of the four tube-plugging evolutions this operating cycle (June 05 to May 06).

Indirect Cost Impact

Radiation Exposure

Columbia's main condenser location exposes personnel to radiation during repairs. Keeping radiation exposure 'as low as reasonably achievable' is everyone's responsibility.

Radiation exposure is closely monitored by Energy Northwest, the Nuclear Regulatory Commission, and the Institute of Nuclear Power Operations. A non-outage month at a top performing boiling water reactor is less than 2 Rem collective radiation exposure, with a total for the year of around 30 Rem. Adding one condenser repair evolution jeopardizes the annual goal of 30 Rem or less.

2.262 Rem/evolution
Collective radiation exposure to Columbia staff and contractors, per tube plugging evolution this operating cycle (June 05 to May 06).

9.048 Rem
Collective radiation exposure to Columbia staff and contractors this operating cycle (June 05 to May 06).

Replacement Power

Columbia conducts tube plugging evolutions at 65% power. Based on typical duration, a tube plugging evolution costs us the equivalent of one day of full power operation. Estimating the value of power of $32.45/megawatt hour produces the following indirect costs.

$1,000,000/evolution
Estimated cost of replacement power per tube plugging evolution.

$4,000,000
Estimated cost of replacement power for tube plugging evolutions this fiscal year (July 05 to June 06)

Costs for 2001 Heavy Oxide Layer Analysis

Columbia's staff had extensive fuel rod corrosion related concerns in the 2001 timeframe. A highly experienced industry team was formed to determine the root cause and initiate corrective actions. Condenser leakage was identified as the root cause.

$1,750,000
Cost associated with fuel scrapings, investigation, and research into heavier than expected fuel oxide layer.

One corrective action from the above investigation was to alter Columbia's chemistry controls to favor fuel protection over radiation source term mitigation. The strategy was followed until the current operating cycle. Oxide formation on the fuel during this test period was normal, thereby validating the root cause determination. Favoring fuel protection created very high radiation source term at Columbia, resulting in increased staff radiation exposure. The impact is difficult to quantify, but very real. Columbia's radiation exposure performance is in the worst quartile in the industry. Columbia is currently the worst plant based on source term measurements. To counteract this, a chemical decontamination of key piping is scheduled for our upcoming outage.

$1,700,000
Approximate cost of chemical decontamination in the upcoming outage to improve radiation source term.

Replacement Power Estimates Since 2000

Lost power generation (associated with main condenser leakage) since January 1, 2001 is equivalent to more than 12.5 days of full power operation. With an estimated value of power of $32.45/megawatt hours, the total cost is substantial.

$12,500,000
Estimated value of replacement power associated with Columbia main condenser leakage events since January 1, 2001.

Conclusion

Various conclusions can be drawn from the above data. In simple terms, the author draws the following underlying conclusion, upon which others can build.

> "The design and resulting poor performance of Columbia's main condenser has produced many direct and indirect costs and continuously challenged our ability to achieve operational performance levels expected of U.S. nuclear power plant operators.

The chronic nature of Columbia's main condenser problem is unlikely to change substantially without addressing the condenser tube material. Failure to address this issue will increase the risk of fuel damage. That fact alone is ample reason to replace the main condenser tubes. Replacement is also in the best interest of efficient financial operation of the plant as evidenced by the costly history of our present condenser equipment."