

# CANDU MAINTENANCE CONFERENCE 1987

## OVERVIEW OF PICKERING NGS UNITS 1 AND 2 RETUBE OUTAGE

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### ABSTRACT

After the Pickering NGS Unit 2 pressure tube failure in August 1983 a decision was made in March 1984 to replace all the pressure tubes from both Unit 1 and 2. This retubing was accomplished over a three year period together with a program of inspection, maintenance and modification on other systems. Equipment was put in a short term mothballed state at the commencement of the outage and a thorough recommissioning of all systems, both old and new, was carried out during restart. Details of each component of the outage are described in references (1) through (16). This paper provides an overview of the program highlighting successes and difficulties encountered and recommending changes for future projects of this kind.

### EVENTS LEADING UP TO THE RETUBE OPERATION

Pickering NGS is an 8 x 540 MWe CANDU station situated approximately 30 miles east of Toronto on the shore of Lake Ontario. Unit 1 was placed in service in 1971 and Unit 8 in 1986. Figure 1 shows the schematic of Pickering NGS-A CANDU reactor core. In 1974, the first leakage from a pressure tube resulting in replacement occurred in Pickering Unit 3. Figure 2 shows the Pickering fuel channel assembly. Location and replacement of that single channel consumed over 100 man-rem and took 6 weeks. Subsequent to that failure an additional 16 channels in Unit 3 and 52 in Unit 4 were replaced over the following 2 years. The dose received per channel was gradually reduced to approximately 16 man-rem over the last few replacements. Based on this actual performance, and using the same techniques, replacement of an entire core would consume over 6,000 man-rem and take over 4 years to carry out.

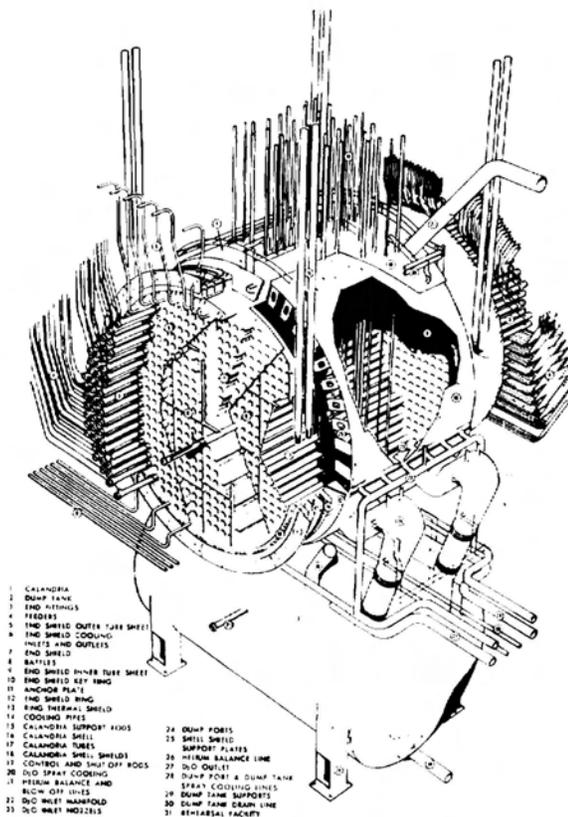


FIGURE 1: CANDU REACTOR ASSEMBLY

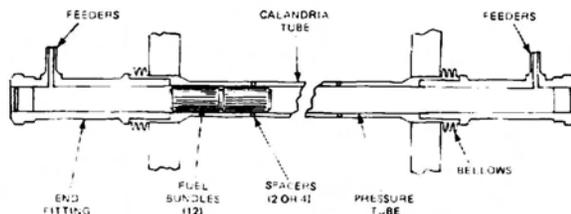


FIGURE 2: FUEL CHANNEL ASSEMBLY

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Accordingly, studies were initiated in 1976 to find methods of reducing the worker exposure and outage time for a full core replacement should it be required. Areas of study included radiation source reduction, shielding, defuelling, replacement process improvements and remotely controlled tooling.

On August 1, 1983, pressure tube G16 in Unit 2 failed, resulting in a major leak of heavy water from the heat transport system. The leak was eventually traced to a crack, approximately 2 m long and 20 mm wide, in one of the pressure tubes.

Analysis indicated that the pressure tube failure resulted from unexpectedly high levels of deuterium in the Zircaloy-2 alloy, and contact between the pressure tube and calandria tube for a period of seven to ten years.

This was the first failure encountered in Units 1 or 2 in over 12 years of service. Unlike all later units (including Units 3 and 4 which had experienced the earlier leakages) these 2 units had Zircaloy-2 pressure tubes. Later units use the stronger Zirconium - 2.5 wt% Niobium.

Because inspections of pressure tubes in Unit 2 and Unit 1 indicated that a significant number of the 12 year-old Zircaloy-2 tubes in these units might fail in a manner similar to G16. It was decided to carry out large scale pressure tube replacement for both reactors. In making this decision in March, 1984, it was considered the fastest means of returning these units to safe reliable and economic service.

### OBJECTIVES SET FOR THE RETUBE PROGRAM

The objective presented to the retube project team was to remove and install to modern standards all 390 pressure tubes from each of Units 1 and 2, with a total group exposure to workers of less than 1,000 man-rem per reactor, over a 2 1/2 year period. Each of the original pressure tubes have contact gamma fields of up to 20,000 R/hr. The general fields on the fuelling machine bridge at the start of the project ranged from 100 to 1,400 mr/hr depending on elevation.

### OVERALL RETUBE PROCESS

The overall retube process logic integrated several areas normally carried out by either Operations or Construction staff. The basic phases were:

- decontamination
- defuelling
- unit preparation
- fuel channel removal
- fuel channel installation.

A brief outline of these phases follows.

### Decontamination (1)

By the use of the CANDECON decontamination process on the primary heat transport system decontamination factors of 5 to 10 were achieved. This result was a significant breakthrough, since it meant that long work durations for an individual worker could be achieved in the vaults prior to reaching radiation dose limits.

### Defuelling

The units were defuelled using the existing fuel handling system, augmented by some special ram adaptors. A total of 4,680 fuel bundles were removed in less than 3 months. There were no significant system failures during this period and no damaged fuel. All fuel was transported to the irradiated fuel storage bay.

### Unit Preparation

After defuelling the units were drained of D<sub>2</sub>O to the headers (Figure 3). Each fuel channel was when individually drained via the fuelling machines. The heat transport system was then refilled with light water, flushed and drained again (2).

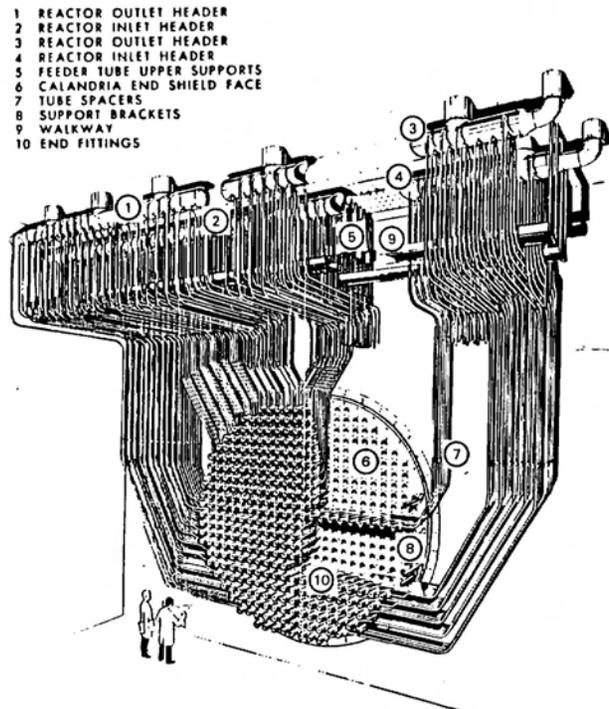


FIGURE 3: FEEDER TUBE ARRANGEMENT

After draining, large vacuum pumps were connected to the heat transport system and a vacuum sufficient to dry up all remaining pockets was drawn. (2)

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Several prerequisite activities were also carried out including the removal of some internal reactor building walls to permit equipment movements and partial disassembly of fixed equipment to provide better access. The unit was isolated from the station containment envelope by constructing a bulkhead between the boiler room and the vacuum duct. This allowed later opening of both air lock doors and greatly facilitated equipment transfers in and out of the reactor building.

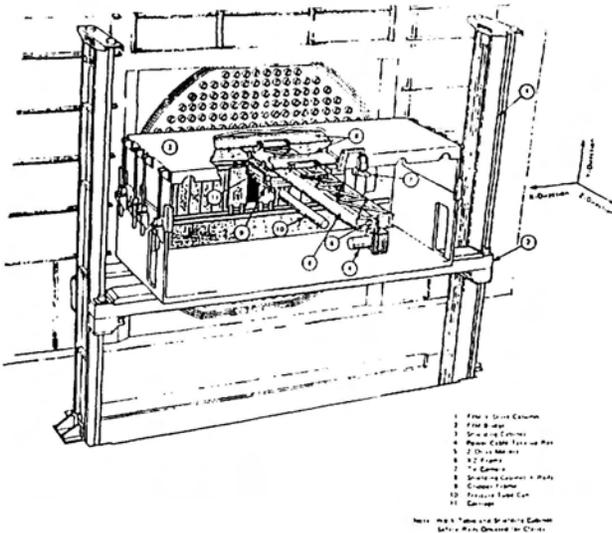


FIGURE 4: RETUBING TOOL CARRIER AT REACTOR FACE



FIGURE 5: PICKERING REACTOR FACE WORK

### Fuel Channel Removal

**Equipment Set-up.** A key feature in establishing a suitable working environment was the 35 metric ton shielding cabinet which was placed on each fuelling machine bridge (Figure 4, 5 and 6). This shielding cabinet was effective in reducing

the radiation fields by a further factor of 10. (6) Within the roof of the shielding cabinet was located either a 1,400 kg capacity hoist, or a retubing tooling carrier (Figure 4). The retubing tooling carrier is a remotely controlled crane with 6 degrees of freedom. A manually operated work table was located on tracks in the floor of the cabinet. The work table provided a 5 degree of freedom platform on which tools were affixed and aligned with each fuel channel.

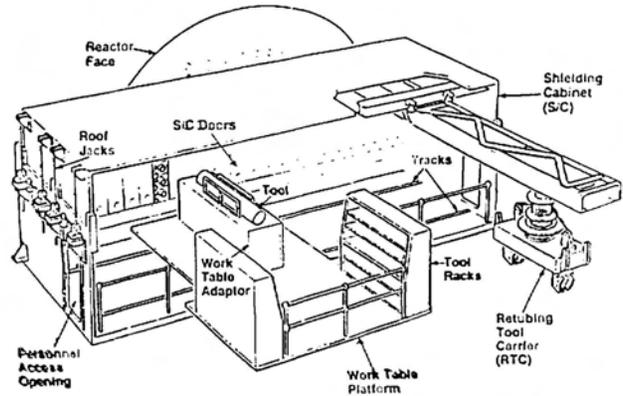


FIGURE 6: SHIELDING CABINET ARRANGEMENT

**Active Component Removal.** Removal of the irradiated end fittings and pressure tubes was accomplished using the remotely controlled retubing tooling carrier (7). The retubing tooling carrier gripped tooling which was attached to the irradiated components while they were still located inside the reactor. Once the vaults were clear of workers, the retubing tooling carrier pulled the component out horizontally and lowered it to the vault floor where it is pushed into an awaiting flask. The flask was then moved through the plant to a transfer area where the irradiated component is pushed into large (175 metric tons) concrete canisters for storage (Figure 7). Eighteen such canisters were required to contain all the components (3). Each canister measured 4 m in diameter and 8 m in length.

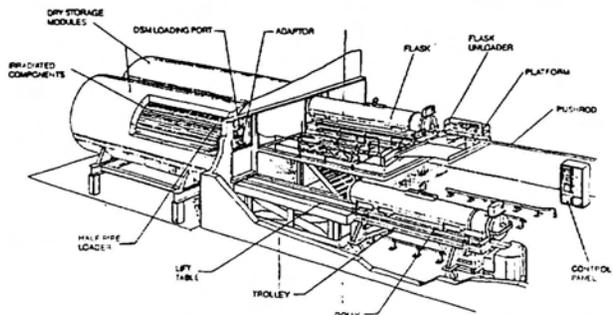


FIGURE 7: ICMS TRANSFER STATION

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Although the only component which needed to be replaced was the pressure tube, at least one of the steel end fittings (Figure 2) was also removed to gain access to the pressure tube. This a total of 780 end fittings and 780 pressure tubes, all highly radio active weighing a total of approximately 100 metric tons were removed.

One of the end fittings was left in the reactor and re-used. The original pressure tube was joined to the end fitting by means of a mechanically rolled joint. Separation was achieved by rapidly heating the pressure tube using induction heating to a very high temperature before heating the steel end fitting. This resulted in the pressure tube being thermally expanded but since it was constrained by the cold end fitting, the tube underwent high temperature yielding. Thus when the tube cooled, it achieved a smaller diameter and separation with the end fitting (4).

### Reinstallation

The reinstallation of the new pressure tube was accomplished in a similar manner to the original construction with the significant exception that the calandria tubes through which the new pressure tubes must pass had already experienced 12 years of service (5). This had resulted in the calandria tubes being distorted from thermal and neutron creep effects. Thus special measures had to be adopted to ensure that no damage occurred to the new straight pressure tubes on installation through the distorted calandria tubes. In addition, special alignment devices were required to ensure proper fit up between the pressure tubes and end fittings.

### RADIATION DOSE MANAGEMENT DURING RETUBE

Significant radiological hazards existed throughout the job. These included:

(a) General background gamma radiation fields outside of the shielded working area of 50 to 150 mr/hr after the heat transport system was decontaminated.

(b) Gamma fields on contact with the old pressure tubes and end fittings components of up to 20,000 R/hr.

(c) Collimated beams of gamma radiation of up to 30 R/hr emanating from the empty latic sites left behind when the end fittings are removed.

(d) Airborne tritium of up to 2 MPC.

(e) Carbon-14 dust generated as a result of using nitrogen in the space between the pressure tube and calandria tube during reactor operation. This dust was in the 1 micron particle size and became easily airborne (12).

(f) Miscellaneous activated particulates of magnetite, and fission products contained inside the pressure tubes and end fittings in the form of a loose powder.

To ensure that any individual worker did not receive exposures greater than site imposed or jurisdictional limits, and to ensure the total worker population dose was minimized, a multi-discipline radiation dose management program was initiated. The various elements of the program were as follows:

Source Removal. The fuel and after the systems were decontaminated using the CANDECON decontamination system, the tritiated heavy water contained in the heat transport and moderator systems was drained.

Shielding. The shielding cabinet was installed and had an additional reduction factor of 10. The overall effect was a general gamma field inside the cabinet of 5 to 15 mr/hr.

Specialized Process and Equipment. Each procedural step required to remove and install the fuel channels was analysed to ensure the least amount of man-hours spent in radiation areas. Tools were custom designed to increase worker efficiency, and reduce the amount of radioactive debris produced. Over 500 different tools were custom designed and developed.

Remote Handling. Removal of the irradiated end fittings and pressure tubes was performed with remote handling devices since the general gamma fields in the vault were far too high for workers to be present during this operation.

Communication. Extension video surveillance of the working areas was used to allow continuous supervision from outside of the radiation areas. In addition, a closed circuit voice communication system was used to talk to workers from the control room.

Tool Proving. A full scale mock-up of the working areas was built (Figure 8). This included one complete level of the reactor building, vaults, fuelling machine bridge shielding cabinets, etc. Full length arrays of fuel channels were used to test out every piece of equipment prior to its use on the actual reactor. This ensured that unproductive time spent in radiation areas as a result of tool failure was minimized (8).

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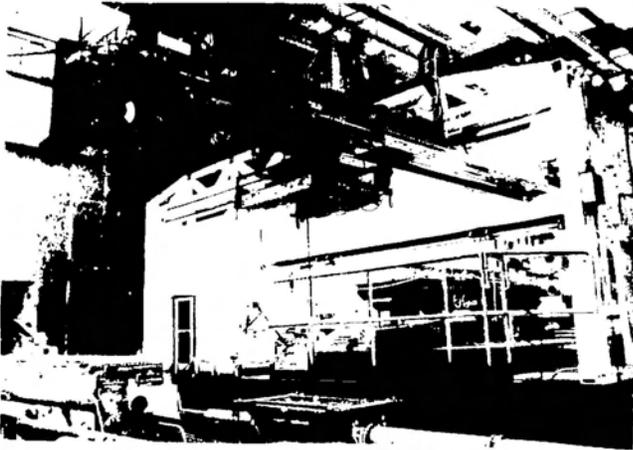


FIGURE 8: EQUIPMENT AT MOCK-UP FACILITY

Training. Every worker that performed jobs inside radiation areas underwent training on the mock-ups using proven tools. In addition, radiological hazard training was performed with dress rehearsals in plastic suits with breathing air supplied. This helped to minimize time in the radiation field thus reducing dose to the workers expenditures.

Protective Clothing. All workers were required to wear specially developed plastic suits with external breathing air supplied. This provided a protection factor of 100 against airborne hazards.

Procedures. All activities performed in radiation areas and in preparation of reactor components were controlled by detailed procedures that covered all aspects of equipment operation as well as safety and quality control. Training was performed using these procedures. In this way unproductive efforts and worker exposure on reactor due to procedural follow-ups and quality control problems are minimized.

### QUALITY ASSURANCE DURING RETUBE

#### Design/Procurement Phase

Although the project is concerned primarily with the replacement of existing components, it was known at the start that due to changing standards, codes and designs over the years, a virtual complete redesign of the components to be replaced would be needed. Therefore, a full quality engineering program was implemented involving new documentation for requirements, conceptual and final designs with the appropriate formal design reviews. In the procurement of reactor components, modern standards of quality assurance/quality control in manufacturing were applied.

#### Construction Phase

As an adaptation of new plant construction quality assurance processes a quality assurance program based on the following elements was followed and combined with radiation dose reduction measures.

(a) Preparation of a very detailed package of information by the site Resident Engineer's Department based on the output of Design with express instructions covering radiological safety and quality control checks.

(b) Workers are trained on realistic mock-ups using the tooling and detailed procedures to be used on the reactor.

(c) The tooling to be used for reactor face work was custom designed to meet the objectives of minimizing worker exposure and handling highly active components

(d) Construction work was performed according to the detailed procedures by qualified tradesmen reporting to the General Superintendent.

(e) Independent verification at quality control hold points was accommodated by Technicians, assigned to the shift crews, being present at the time tradesmen perform critical tasks. The technicians reported to an engineer on shift who was responsible for accepting or rejecting deviations. Written records were kept of all quality control checks and deviations.

(f) The recommissioning of the unit was performed to the same standard as a new unit.

(g) Internal audits of adherence to procedures were carried out. The regulatory agency (Atomic Energy Control Board) also performed audits on the adequacy of and adherence to radiation protection and quality assurance procedures.

### RESULTS

The following summarizes the achievements of the retube program vs the original objectives.

#### Conventional Safety

The station operation target in terms of lost time injury frequencies is less than 2 per  $10^6$  man hours worked. Nearly 2 million man hours were worked on the project and 2 lost time accidents suffered, giving a frequency of 1 per  $10^6$  man hours - better than the station objective.

#### Radiation Safety

In 1984 a target was established to complete both units retubing for no more than 1,000 rem. Both units here now have been completed for approximately 650 rem - a remarkable achievement of less than 850 m/rem per channel.

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## Costs

The original budget excluding recommissioning costs 518 M\$ the final estimate is now 420 M\$ for completion.

## Schedule

The original schedule had Unit 1 returning to service in November 1986 and Unit 2 in February 1987. In actual fact Unit 1 returned to service in October 1987 (11 months late) and Unit 2 is scheduled to be returned to service in May 1988 (13 months late) (Figure 9).

### PICKERING UNITS 1 & 2 RETUBING SCHEDULE

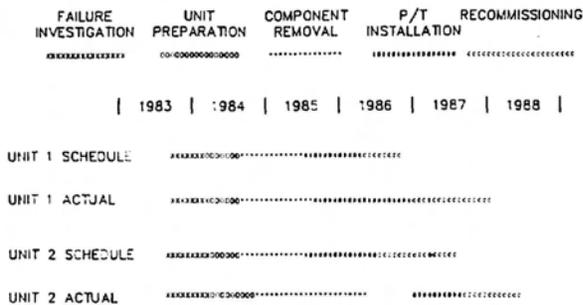


FIGURE 9: PICKERING UNITS 1 AND 2 RETUBING SCHEDULE

There were numerous contributors to the delays and amongst these the following were major factors:

## Technical Problems

Of the technical problems such as heat transport crud, (9) and general tooling difficulties, carbon-14 (11) proved to be the most difficult time consuming. It alone accounts for about 4 months of project delays. Recent analysis of the actual C-14 substance has revealed that when heated to 250 - 300°C, CO<sub>2</sub> is given off carrying the C-14 off as a monitorable gas. This should allow development of a method to remove solid C<sub>14</sub> prior to any future retubing programs and has also permitted decontamination of feeder cabinet areas on P1 as the unit is operated (12).

## Organizational Problems

(The basic field organizational structure is shown in Figure 10).

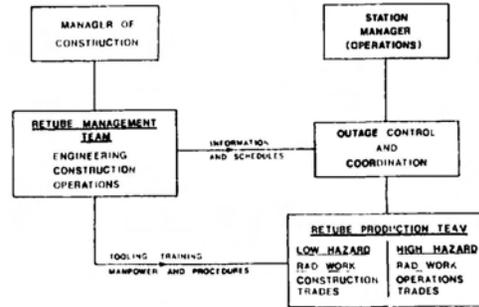


FIGURE 10: RETUBING ORGANIZATION

To carry out the field engineering and project control a unit combining staff from engineering, Construction and Operations, about 50 in total, was established. This unit produced the detailed procedures for reactor work, organized tool proving and maintenance and created the manpower selection and training program.

The replacement of the fuel channels, although setting the critical path for the outage, was non-the-less only dealing with one of many systems in each unit which required work during the outage.

The trades manpower provided by Operations came out of the normal station compliment and higher priority work with other units tended to draw on this resource. Although critical path activities were never actually curtailed due to this problem, the project schedule was considerably delayed by its effect. Unit 2 being the lowest priority on the station suffered from extended periods of inactivity.

For future outages of this type it is recommended that a dedicated team of Operations and Construction trades and supervision be established with total independence from other station priorities. In addition only one outage of this magnitude should be tackled at a time.

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### PICKERING UPGRADE PROGRAM

#### General Description

When the decision was made in March 1984, to retube both Units 1 and 2 at Pickering NGS, another program was instituted to be performed concurrently. This program designated "PICK-UP" (Pickering Upgrade), had the objective of ensuring a further 30 years of safe, reliable unit operation - post retube. It consisted of four components:

#### Lay-up (Short Term Mothballing)

To ensure minimal degradation of equipment during the four year retubing outage period.

#### Inspection and Maintenance

Inspection of the major unit components for the development of maintenance/repair programs to ensure future safe, reliable operation.

#### Modifications

Installation of new and previously planned system modifications to ensure long-term licensing and safe, reliable operation.

#### Recommissioning

To ensure that all systems, both old and new, meet the design requirements and are placed in service as safely and expeditiously as possible.

The Lay-up Process (13). Where possible, systems were maintained in an operational state. If that was not practical, an environment was maintained within the system to inhibit degradation. Typical examples of actions taken were:

(a) Service water, air and electrical distribution systems were maintained in limited service.

(b) Steam generators, feed heaters and other systems were filled with hydrazine treated water.

(c) Primary heat transport and main steam systems were filled with nitrogen gas, and

(d) Selected service water heat exchangers were drained and dried.

The inspections performed during the recommissioning phase have shown that the lay-up program was generally successful in preventing any major degradation during the four year outage period.

The Inspection and Maintenance Program (15). Seventy inspection programs of major systems and equipment were performed. The systems can be characterized into two main groups: Nuclear Systems and Conventional Systems. Our findings were as follows:

1. The Nuclear Systems. The nuclear systems were generally found to be in good condition, although components subject to wear or dry-out were prudently replaced. The steam generators tubes and drum internals were in good condition, and a tube sheet sludge removal test was performed with acceptable success.

The main pumps and motors were found to be in good condition, but their seals were replaced due to crud build up from the Candecon process. The significant nuclear-related valves were in good condition, but some relief valves needed seat repairs and recalibration.

The civil structures were extensively examined and some minor repairs were done to ensure longevity. All nuclear related heat exchangers were found to be in good condition, as was the main piping and electrical systems.

The fuelling machine heads were totally overhauled and rewiring was performed to ensure qualification against any future possibility of steam and water damage.

Extensive inspections, using remotely manipulated video cameras and ultra-sonic devices, were performed to assess the condition of nuclear systems within the calandria vault, with particular attention paid to the biological shield cooling system.

Some carbon steel pipe hangers supporting the inlet moderator piping were found to be broken. The failure was determined to be due to stress corrosion cracking, associated with a wet atmosphere from known biological shield cooling pipe leaks. The pipe hangers were replaced with stainless steel supports, and extensive stress analysis was performed to ensure the integrity of the stainless steel steel moderator piping.

The biological shield cooling pipe leaks have been closely monitored since 1985, and internal sealing agents have been used to close cracks. While these leaks are not presently of critical concern for Pickering Units 1 and 2, there is a potential concern for this problem becoming serious in the future, and extensive studies are ongoing to either reinforce the outer walls of the piping or replace piping sections.

2. The Conventional System. The conventional systems were generally in an acceptable condition but required extensive cleaning and recalibration.

The turbine/generator is in good condition and no particular actions were needed. The main steam and feedwater lines were found acceptable showing minor erosion/corrosion signs. The electrical systems were also fit for service, but it was considered prudent to extensively clean the switchgear and recalibrate. Elastomeric components showed some signs of

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degradation and were replaced. Various control and relief valves showed a drift in calibration and were re-set.

The main steam safety valves exhibited deterioration and repairs were made. Also, the pumps and motors associated with boiler feed and service water systems required repair. Cavitation and silt problems were generally evident in those conventional pumps in contact with the Lake Ontario water.

Heat exchangers on the conventional side, were found to be in a fair to poor condition. In general, heat exchangers in contact with lake water showed signs of degradation. The main condensers were retubed and the shield cooling heat exchangers were also replaced. The reasons for this problem are attributed to the silt content of the secondary cooling water, and the intake system design is being studied to determine whether modifications are economic.

3. System Modifications. The long retubing outage provided a idea opportunity to install both safety and process system modifications which had either been committed prior to the Unit 2 G16 pressure tube failure or were deemed necessary to ensure safe reliable operation for 30 years post retube. Seventy such modifications were installed during the outage the most notable being:

### - Major Safety System Modification

- High pressure emergency coolant injection system installation. An adaption of the Pickering NGS-B injection system for better reliability and effectiveness.

- Low Pressure emergency coolant recirculation modification. Modification of original collection route and recirculation circuit to provide better reliability.

- Improved shutdown capability. Installation of ten additional shut-off rods in place of adjusters.

- New in-core flux detector assemblies for improved reliability.

- New post loss of coolant accident hydrogen ignition system installation.

- Upgraded annulus gas system for pressure tube leak detection.

- New trip parameters. Primary heat transport low and very low pressure trips.

- Nitrogen 16 gamma compensation for high power trip.

- Post loss of coolant accident modification (automated system isolation and radiation shielding).

- Site electrical system installation.

### - Major Process System Modification.

- Shut-off rod improved partial drop test facility.

- Channelization of start-up instrumentation.

- Enhanced computer annunciation system (installation of new control room computers).

- New air lock door actuators.

- Fuelling machine improvements.

- Turbine/generator electrical anticipatory control.

- Addition of startup steam motorized valves.

- New boiler feed chemical instrumentation.

- New main generator temperature monitoring equipment.

- Upgrade of the breathing air system.

- New turbine air extraction pump installation.

- Boiler blow down freezing protection.

- Removal of emergency gland cooler.

- Improvements in turbovisory equipment.

- Class 1 power overload protection.

All the modifications were engineered and equipment purchase during the first half of the outage. Wiring changes were specified and detailed on system wiring printouts. The major changes such as the emergency coolant injection and recovery systems were performed by Construction forces while Operations performed the smaller packages and the electrical tie-ins. Construction required considerable Operations support in terms of work and radiation protection. This demand on operational forces stretched its capability to the point that work was often extremely slow to start and frequent delays often occurred. Once again a dedicated work force free of the demands from operating units would have improved the situation.

Recommissioning (14). Recommissioning and performance tests were carried out on both old and new systems to ensure that all could meet their design requirements. Special emphasis was placed on ensuring on the quality of the special safety systems was up to present day standards. A set of detailed commissioning specifications were drawn up for every system and testing was specified to ensure all systems demonstrated they could meet these specifications.

This proved an interesting exercise, since many of the older systems had never been analyzed or tested to this very high level during original commissioning in the late 60's

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and early 70's. Several improvements were identified; for instance, water hammer and air entrainment possibilities became evident during the high pressure emergency coolant injection and recovery system analysis and testing. Shutdown system wiring checks revealed discrepancies from drawings, however, no compromise of safety was found.

Problems of long term inactivity were also evident on the older systems. Relief and control valve settings had drifted, and valve seats were damaged, electrical relay contacts required cleaning, large isolating valves had become stuck closed, and valve packing required tightening or replacing.

The large number of system modifications carried out required that a complete review of all operating documentation be performed. The training simulator had to be extensively modified and a program of operating license requalification, including examinations, was executed.

The actual commissioning process followed a reasonably conventional path with the majority of safety and nuclear systems being checked out prior to fuel load (Figure 10). The ten new shut-off rods performed well during this initial commissioning phase. A full set of completion assurance reviews were held for each system with designers and regulators present.

Almost three years to the day since defuelling began, fuel loading was performed from within the retubing shielded cabinet to minimize radiation dose to the workers.

New heavy water was added to the primary heat transport system and a hydrostatic pressure test performed at 2 000 psig. This proved somewhat difficult due to dried out valve packing (a result of the three year dry lay-up period), leaking pump seals and passing relief valves.

The reactor building was pressure tested to 6 psig. The minor concrete and containment repairs which had been performed during the pick-up program paid off, since the leakage rate was less than the original 1970 commissioning test. The bulkhead, isolating the unit from the station containment envelope for retubing, was removed and the moderator system filled with the original charge of tritiated heavy water. A period of hot commissioning was then performed, during which all the temperature dependent safety parameters were checked out and process system hot control devices exercised.

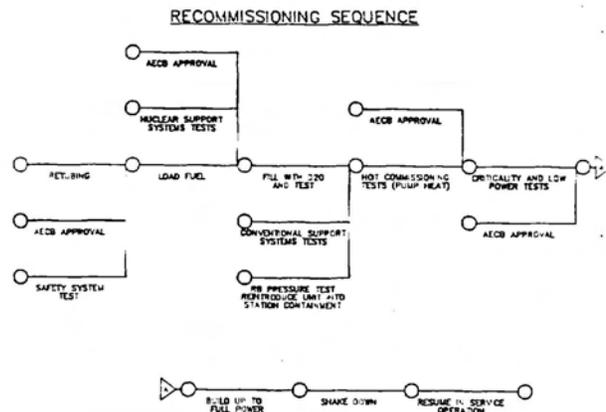


FIGURE 11: RECOMMISSIONING SEQUENCE

The commissioning process took three months longer than anticipated primarily due to problems uncovered during the process and a shortage of Operations manpower. The demand on Operator, Control Maintenance and Mechanical trades is very intensive during the six months prior and three months after first criticality. In addition, at one time the engineering staff (44 engineers) were working up to 30% overtime in order to cope with the large volume of problems encountered.

The recommissioning exercise taught both Engineering and Operations many lessons that will be incorporated into Unit 2's program. The performance of such a rigorous commissioning sequence, however, has provided a great deal of confidence in the quality of the rebuilt and upgraded unit.

First criticality was achieved on July 16, 1987 and first electricity was produced on September 4, 1987, with full power being achieved on September 24, and returned to service on October 1, 1987.

Unit 2 is scheduled for fuel load on December 1, 1987, and return to service May 1988.

### RECOMMENDATIONS FOR FUTURE RETUBE OUTAGES

Significant outage time can be saved by further development of the retubing process to optimize tooling and sequencing of activities. Development of this capability is underway.

Significant outage time can be saved by setting up a dedicated field project team and giving them full responsibility for the unit being rehabilitated. The project team must have dedicated staff including licensed supervision and Operators plus Construction and Operations trades. The project team should report to a dedicated field manager who will be accountable for the safe, timely and economic execution of the rehabilitation program. The unit itself should be isolated from the operating plant to the optimum extent and should be provided with dedicated support facilities.

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Recommissioning of the unit should start earlier in the outage with upgrading modification, inspections and lay-up application being phased in at the very beginning. This can only be achieved if the next retubing outage is planned ahead of time. This leads to the conclusion that Ontario Hydro must develop a realistic retubing outage sequence consistent with predicted pressure tube life, system requirements and manpower constraints. From the experience of P1 and 2 it is highly recommended that only one retube outage should be tackled at one site at any one time.

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