DARLINGTON UNIT #2 RETURN TO SERVICE PROGRAM

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FORMATION OF THE UNIT #2 RESTART TEAM

In August 1991, the Darlington Steering Committee determined that there was a need to form a team to review and specify what actions had to be taken to safely return Unit 2 to service as there had been significant progress in the understanding of the causes of the fuel damage mechanism. This Restart Team was to report to the Darlington Technical Manager. Members of the team provided the expertise of several groups within Darlington Operations as well as Ontario Hydro Inspection and Maintenance, Darlington Engineering Department (DED), Darlington Construction, AECL CANDU, Nuclear Engineering Department (NED) and Nuclear Safety Department (NSD).

The mandate of the restart team was to specify the actions needed to assure that pressure tubes, core fuel, reactor components and other systems (i.e. turbine generator rotor) were satisfactory to allow the restart of unit 2.

The objectives were to:

1. Determine the state of the Unit 2 core fuel and refuel as necessary
2. Determine the state of the Unit 2 pressure tubes (PT) and disposition/replace PT's as necessary
3. Complete all necessary modifications to the Primary Heat Transport (PHT) system on Unit 2 as specified by DED to minimize or eliminate further fuel/PT damage
4. Review all other ECN's and mandatory work to safely return Unit 2 to service.
5. Provide the necessary technical and administrative support to implement the required actions on Unit 2.

The original target date for completing this work on Unit 2 and returning it to service was March 1992. Because of uncertainties related to the design change (FIX) on the PHT system, manpower shortages with FH panel and field qualified operators, commissioning workload and priorities on other units, Unit 2 will probably not return to service until September 1992.

INSPECTION STRATEGY

One of the initial activities of the team was to develop a strategy and program for the reactor inspections that would be necessary, as this was recognized as being the key to determining what work would be required to restart the unit. The goal of the inspection program was defined as assuring the continued reliable, safe operation of the unit 2 fuel and fuel channels, assuming that modifications to equipment and operating procedures would ensure no future damage would occur.

The strategy relied upon fuel examination from the core as a means of indicating where fuel damage had occurred and where potential pressure tube damage may have also occurred.

The reactor inspection program that evolved from this strategy consisted of two phases:

Phase 1: Determine severity of the fuel and pressure tube (P/T) damage by:
- a) Inspecting suspect damaged fuel in the Irradiated Fuel Bay (IFB)
- b) CIGAR inspection of channels with known fuel damage
- c) Developing a relationship between fuel & fuel channel damage

Phase 2: Determine the extent of the fuel and P/T damage by:
- a) Mapping out areas in the reactor with known damage
- b) CIGAR inspection to assess pressure tube damage

Following completion of the inspection program, pressure tubes could be replaced if necessary, and reactivity refuelling of the reactor would be performed to return the unit to 100 % F.P operation

ACCEPTANCE CRITERIA FOR INSPECTION

Fuel inspections were directed primarily at determining and classifying the extent of wear/damage to fuel removed from the core, and as such there was no "acceptance" level in the conventional sense. Pressure tubes, on the other hand, were assessed according to the methods that have been developed and accepted by the jurisdictions.

Number of Pressure Tubes To Replace

The plan to restart unit 2 was based on replacing a small number of pressure tubes. It was felt at the time that the fuel damage was not wide spread and therefore may not have been severe enough to cause damage to a large number of pressure tubes. Fuel bundle endplate cracks were totally restricted to columns 12 & 13, rows H to R and inlet bundle bearing pad spacer sleeve interaction (SSI) varied from Type 1 (no evidence of SSI) to Type 4 (25 % wear). Therefore 6 channels were arbitrarily assumed to require replacement for planning purposes. These pressure tubes were scheduled to be replaced during the installation of any modifications or changes to the reactor/PHT systems.

MAJOR CONSTRAINTS

Station Status as of November 1990

DNGS Unit 2 was the lead unit at Darlington. It was at 100% full power for approximately 130 days.

Status of Other Units:

U1 - Phase "B" Commissioning in progress (critical, low power)
U3 & U4 - Under construction

West Service Area (WFFAA) - available for service with some commissioning remaining

East Service Area (EFFAA) - under construction

Fuelling Machine Trollies - T3/4 - commissioned and in-service
- T1/2 - commissioning in progress
- T5/6 - under construction

In summary, the station was in the early stages of its operating life and therefore really not ready to handle damaged fuel such as was discovered in 2N12.

History And Condition Of N12

The DNGS Unit 2 N12 incident occurred on Nov.30, 1990 at approximately 2:00 a.m. during a fuel shuffling operation where 4 fuel bundles removed from channel 2Y08 were being inserted into channel 2N12. Fuel shuffling is the movement of fuel from outer lower power channels into the centre higher power channels for reactivity and increased fuel economy. The fuel carrier with irradiated fuel (IF) bundles # 12 & 13 from channel Y08 stalled short of it's normal forward position in channel N12. The fuel carrier was retracted and the shield plug installation was attempted in preparation to close up the channel. The shield plug also stopped short of it's normal forward position.

See Figure 1. Fuel Channel Components.

The shield plug was removed and stored in the Fuelling Machine (FM) head #4 and the normal closure was inserted in an effort to close up the channel. The closure plug could not be inserted and rotated to it's normal locked position of approximately 70 degrees. Attempts were made over approximately a 2 week period to install the closure plug by using a series of flushing,rotating and pushing motions to lock the closure plug. The spare closure (12 lug, reduced diameter soft seal) was finally inserted to approximately 61 degrees (58 degrees is considered locked) but it did not seal tightly.

The reactor was shut down on December 22, 1990 to install a maintenance cap on N12E so that the fuelling machine could be removed from the channel and the reactor could return to power.

The leakrate from N12E at this time was estimated to be approximately 30 l/min by using the rise in the level of the FM storage tank.

The first attempt to install a maintenance cap on N12E was on Dec.27/90. When the FM head was backed off the channel, the leakrate was estimated to be approximately 20 l/min using the PHT storage tank level change. Radiation fields measured near the closure plug of N12E were approximately 13 R/hr. The radiation fields were higher than anticipated and therefore the FM head was placed back onto the channel to contain the leak. A shielded platform was fabricated and 3 crews of mechanical maintainers were trained on maintenance cap installation.

On January 4, 1991 a second attempt was made to install the maintenance cap on N12E. The FM head was backed off the channel, the maintenance platform was placed on the bridge, and the cap was successfully installed within 3 hours. Approximately 3 MG of D_2O drained out of the PHT system during the maintenance cap installation. This D_2O was collected in the PHT recovery trench under Unit 2 and pumped to the cleanup and storage system in the heavy water management building. A radiation survey of N12E after the cap was installed showed a contact dose rate of approximately 600 R/hour at the bottom of the endfitting at the closure plug seal face area. This indicated that fuel bundle debris was trapped at the seal face area.

The unit 2 vault and FM duct was then successfully decontaminated by service maintenance crews using high efficiency particulate filter (HEPA) vacuum cleaners and washing the floors. The vault

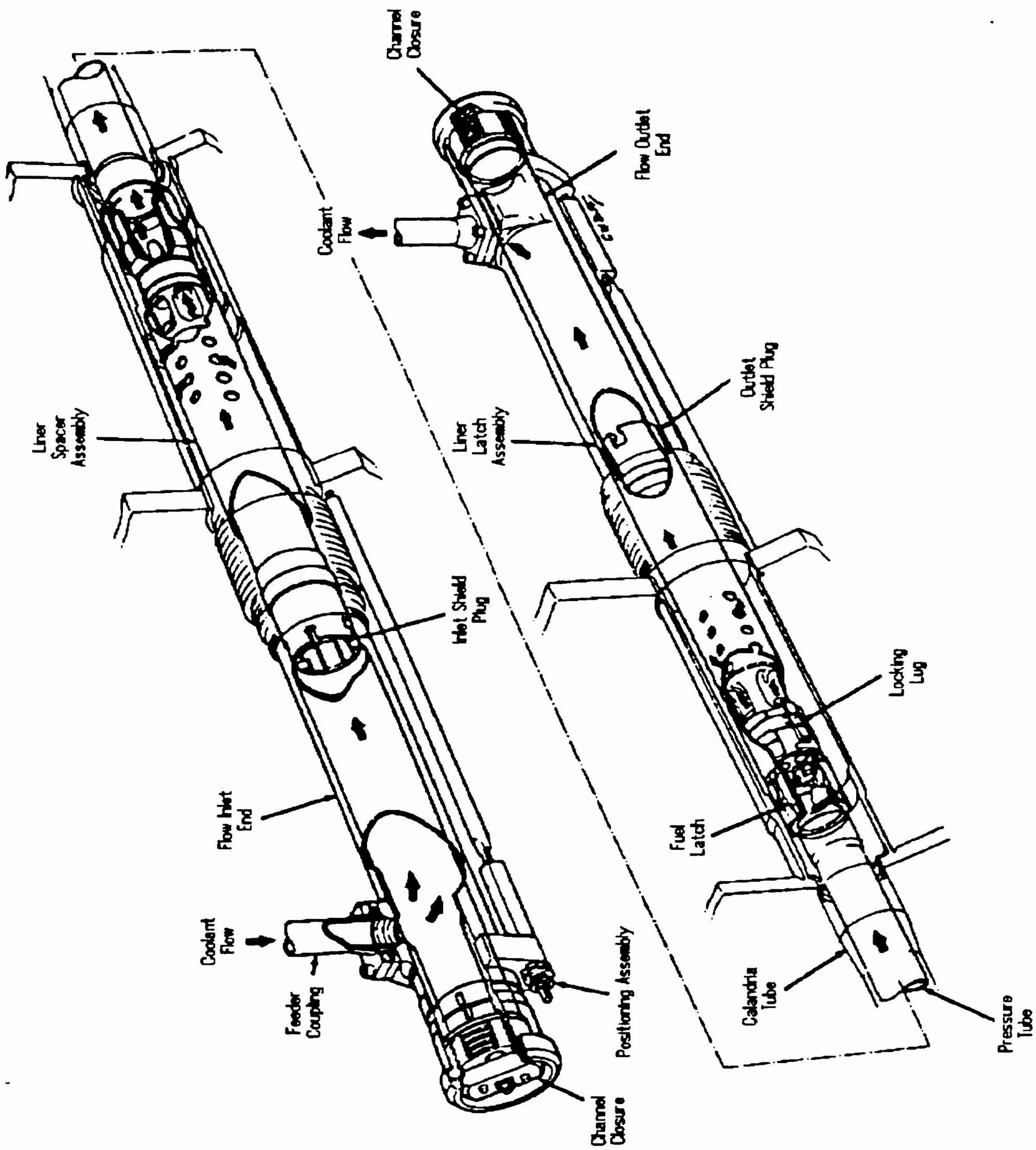


Figure 1

Fuel Channel Components

floor was then checked for contamination. The maslin mop smears picked up only approximately 10,000 CPM thus confirming the success of the decontamination effort.

The radiation dose received by the six man cleanup crew during the decontamination of the unit 2 vault and FM duct cleanup was less than approximately 20 mrem.

On January 8, 1991 the reactor was returned to a derated power level of 65% F.P. due to lack of reactivity. It was not possible to fuel as there was only one FM trolley commissioned and available for service (T3/4). The FM trolley (T3/4) used on N12 was taken to the west service area (WFFAA) to discharge the fuel from Y08. The fuel inspection in the reception bay showed pieces of fuel elements jammed into the end of the fuel bundles from channel Y08. The elements were later identified as elements from N12 bundle # 1. This was the first view of the fuel damage in channel N12.

See Figure 2. Picture of Fuel Carrier with fuel fragments.

See Figure 3. Sketch of suspected fuel debris in 2N12E.

The unit was shutdown on January 12, 1991 as soon as the fragments from N12 were discovered in the Y08 fuel bundles. The unit has remained shutdown since then for fuel damage investigation. Trolley (T3/4) was parked in the WFFAA for decontamination and maintenance. The radiation measurements on the trolley indicated 200,000 to 300,000 CPM of loose contamination on the head and trolley. The trolley and FM head (H4) took approximately 2 weeks to decontaminate and test before it could be returned to unit 2.

Channel Q12 Inspection And Refuelling

A program was set up to video the outlet bundles of 8 channels (using a CIGAR system modified for TV inspections) with similar feeder pipe characteristics as N12. Two channels (K12 & Q12) showed cracked end plates in the #1 bundles.

An attempt was made to remove the fuel from channel Q12 for inspection in the reception bay. FM head # 4 was test operated and the magazine positions were visually checked before going to channel Q12. During the fuelling operation on channel Q12, small pieces of fuel sheath debris were pushed into the channel from the FM. This debris had been left in the FM during the handling of the broken fuel from N12. This caused a premature stall of the fuel carrier and thus the fuelling operation was aborted. The closure plug was inserted into the channel but it could not be rotated to it's normal rotary position of 70 degrees. The channel had a minor leak when the FM head was removed.

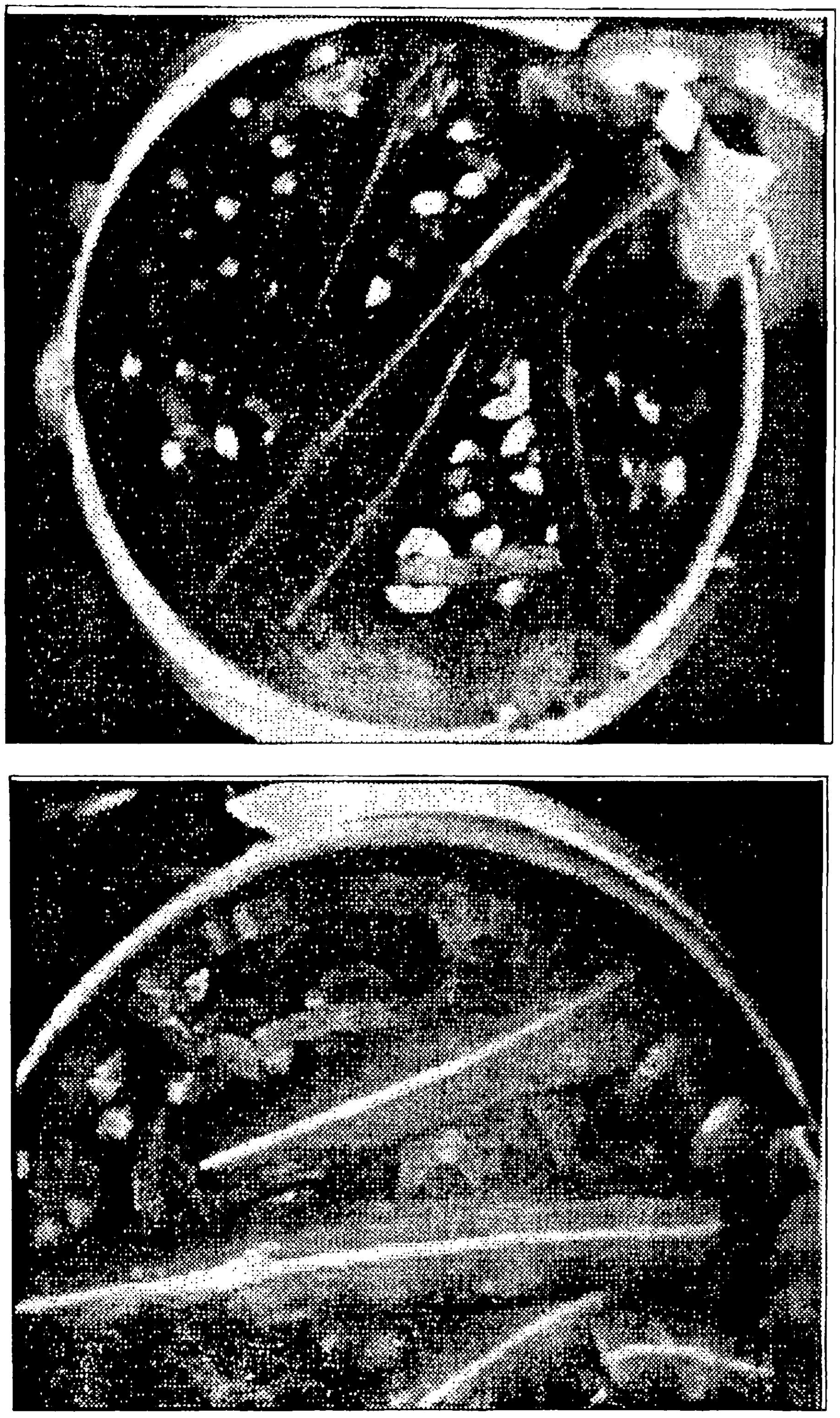


Figure 2

Fuel Carrier with Fragments

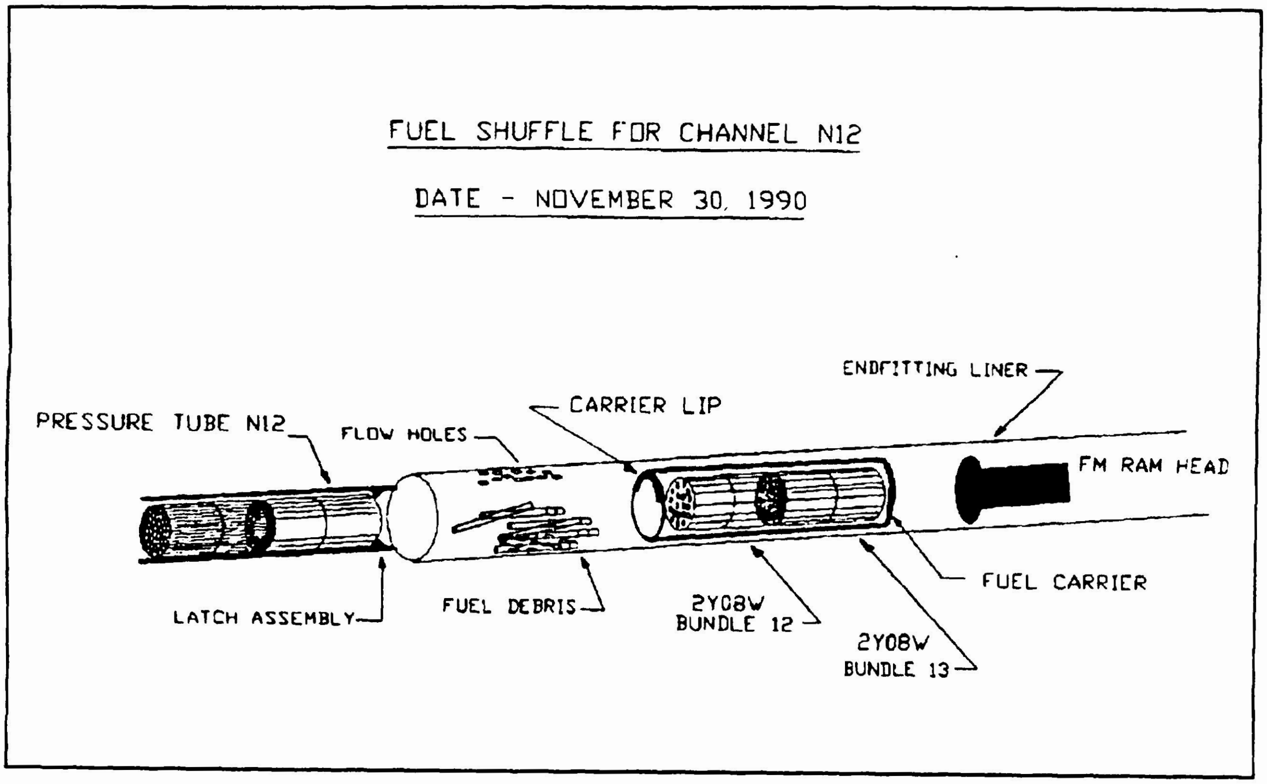


Figure 3

Suspected Debris in 2N12E

The FM was loaded with an end fitting debris scoop and the CIGAR closure plug and returned to Q12E to CIGAR video and scoop the endfitting. The debris was successfully scooped from the endfitting. A 4 lug closure originally manufactured by G.E. and shipped to site for installation into N12E was installed into Q12E and stopped the D_2O leak. This closure plug has 4 lugs at the back of the body and an elastomer seal face thus making it very debris tolerant.

See Figure 4. Picture of 4 lug closure.

It was decided at this time that FM Head # 4 was not reliable because of the potential that more debris could come out of the magazine. A spare head was shipped to site from G.E. Until this time there were no spare operational heads at site. Head # 7 was installed and tested on trolley T3/4 and placed into service in March of 1991.

The fuelling program was then continued and several channels were refuelled on unit # 2 including Q12 and K12.

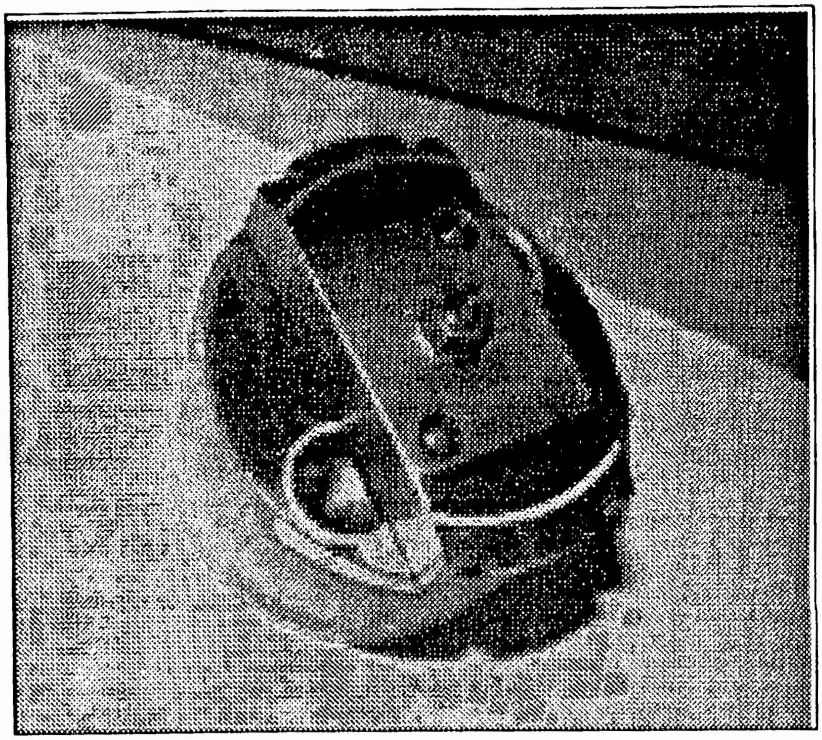
At this time only one trolley (T3/4) was available for service. A second trolley (T1/2) was still undergoing commissioning tests, therefore, the fuel damage investigation program was limited to one trolley (T3/4).

Another CIGAR video campaign was undertaken in an attempt to map out the extent of fuel damage in the unit 2 core. Approximately 37 more channels were CIGARED (video) with 5 channels showing crack-like indications in the bundle # 1 endplates. Several of these channels were then refuelled and the discharged fuel was inspected in the reception bay. Only 2 of these 5 suspect channels actually had cracked endplates (J13 & R13).

Fuel Bundle Inspection And IFB

Early in the N12 program it was determined that the irradiated fuel bay and reception bay were a critical resource (bottle neck) in the fuel damage investigation. The west irradiated fuel bay (IFB) and reception bay were still undergoing some commissioning during the initial fuel shuffle on unit 2 because very little fuel was required to be discharged to the reception bay. The east service area (IFB and reception bay) was not in service (scheduled commissioning completion date is Jan 1993).

When the damaged fuel was discovered in N12 a large scale program had to be implemented to allow rapid unloading and inspection of a large number of irradiated fuel bundles. Also, irradiated fuel shipments to CRL were required to perform destructive fuel bundle inspections. This large scale fuel discharge, inspection and



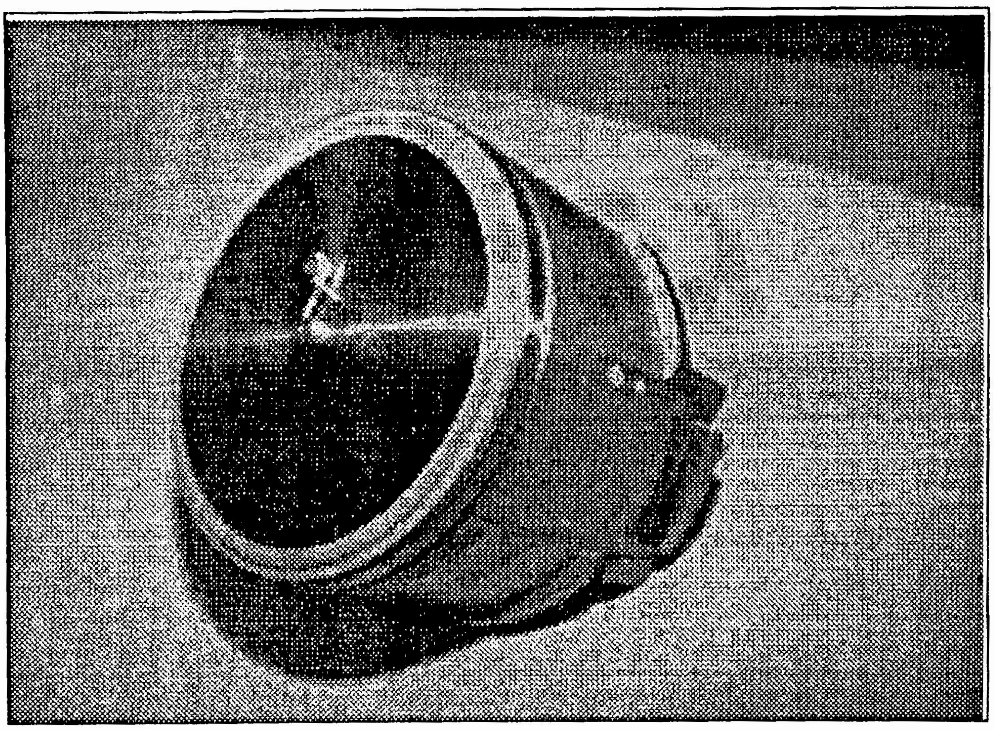


Figure 4

4 Lug Closure Plug

shipping program required a large number of fuel handling field operators and support staff and several months to implement. Some of the new pieces of equipment installed were a module unloader, two inspection facilities with bundle rotators, underwater cameras etc., a separate inspection building for the fuel inspection personnel computers and records and shipping flask decontamination and unloading facilities.

The fuel inspection and documentation facilities can presently unload, inspect, document and reload approximately 8 - 10 bundles per day. This inspection rate is adequate to keep up with fuelling on two units at a time. When units 3 and 4 come on line, it is anticipated that the bundle inspection requirements will reduce substantially.

OTHER CONSTRAINTS

A test program was developed for Unit 2 to determine the reactor/PHT operating conditions that lead to fuel damage. Special instrumentation was attached to PHT headers, feeders and channel closure plugs to assess pressure pulsations in various operating conditions for the reactor.

Prior to the unit 2 reactor test, the inlet ends of channels C10 & K13 were CIGAR inspected (UT) to provide assurance that the pressure tubes were fit for operation. Channel C10 had minor indications but was acceptable for service. Channel K13 had fret marks up to approximately 0.5 mm depth in the inlet bundle (bundle #13) position. This channel was assessed to be acceptable for the duration of the test.

The 4 lug closure plug in channel Q12E was rated at only 4 MPA therefore it had to be removed before unit 2 could be placed in the zero power hot state (10 MPa pressure and 265 Deg. C.)for the test starting in July 1991.

Preparations were made to freeze off and refurbish Q12E seal face so that the 4 lug closure could be removed and a normal 16 lug closure installed. Before the channel feeders could be frozen, the flow restricting shield plug had to be tested on the rehearsal facility (SARF) before going to the unit. The testing on SARF was used to confirm both automatic sequences and mechanical installation. This was the first time that an in-service channel at Darlington was isolated for seal face refurbishing. The channel feeders were successfully frozen and the channel seal face was refurbished.

The test program on unit 2 involved taking the reactor critical to 0.1% F.P. and heating up the PHT to 265 degrees C. This test ran for 2 weeks and provided valuable information on channel vibrations and pulsations.

MAJOR ACCOMPLISHMENTS

Replication Technique

The unit 2 restart program started in September 1991 with fuelling selected channels to map out the extent of damage in the core. This was called "core characterization". This program continued until about October 1991 when all fuelling was stopped to permit unit 3 bulkhead removal in the FM duct and FM trolley power track extension to the East FFAA. This construction and fuel handling commissioning work was completed in January 1992.

During the power track extension work, the fret marks identified earlier in channel K13 were examined using the "Replication Technique" developed at CRL. This was the first time that a replication was attempted on a pressure tube in a fuelled core. This technique involved taking a mold of the inside of the pressure tube at the fret mark locations. The mold was then removed from the pressure tube and the surface of the mold is scanned with a laser profilometer. A computer attached to the laser profilometer produced 2 and 3 dimensional contour maps of the inside of the pressure tube. From these maps, the depth, length, root radius etc. of the fret marks were determined. This is a good technique to support CIGAR inspections, as CIGAR inspections cannot presently provide root radii measurements.

Replication may be used later in the unit 2 return to service program to help disposition and thus minimize the number of pressure tube changes.

Channel K13 SFCR

Channel K13 had a fret mark of approximately 0.5 mm depth and therefore it was decided to change this pressure tube during the power track outage. Removing the pressure tube at this time also provided an opportunity to prove the techniques and tooling developed for Darlington fuel channel replacement. This channel was replaced in approximately 2 weeks by a dedicated day crew with a total accumulated radiation dose to the workers of less than 1 Rem.

Channel K13 has been shipped to CRL for further inspection.

U2 Core Characterization

Channel N12 was initially scheduled to be defuelled in Sept. 1991 before the power track extension work was started in the FM duct by Construction workers. It was felt that with the potential for spread of contamination in the unit 2 vault and FM duct that N12 should be defuelled after the Construction and commissioning work on the power tracks was completed.

Unit 2 fuelling resumed in January 1992. This fuelling was part of the initial core characterization program. Approximately 20 channels (13 bundle pushes) were completed before FM head #4 was placed back into service to start defuelling N12. FM head #4 which had been heavily contaminated during the original N12 event, was to be used for N12 defuelling to avoid contaminating other FM heads.

Unit 1 was operating at this time and required reactivity fuelling. Since unit 2 fuelling was second priority at the station, the fuelling rate on unit 2 was substantially reduced.

Defuelling Channel 2N12

One of the activities that was key to the restart of unit 2 was the defuelling of channel N12. This was the channel where the fuel damage problem was first discovered. The schedule for the defuelling and CIGAR inspection of channel N12 was dictated by corporate priorities, Fuel Handling system capability, fuel handling operator availability, tooling and procedure development necessary for the special operations.

See Figure 5. N12 Defuelling Overview.

Plans were in place to start the preliminary work to defuel N12 on Feb. 15, 1992. The basic guidelines for defuelling N12 were as follows:

1) There would be a dedicated Mechanical Maintenance crew to remove the maintenance cap from N12E.
2) There would be a dedicated fuelling machine operator for the N12 defuelling program.
3) Work was to be done on dayshift ONLY.
4) There would be a dedicated Technical Section group to provide work plans and technical support for the N12 defuelling program.
5) Channel N12E would be CIGAR videoed after each major step of the defuelling program.
6) All major steps of the defuelling program were to be discussed with the affected work groups before field-work started.

Preparations were made to start the removal of the maintenance cap on N12E on February 21, 1992. The shielded maintenance platform was moved into the vault and placed on the east FM bridge. A collection trough was placed on the east reactor face to collect

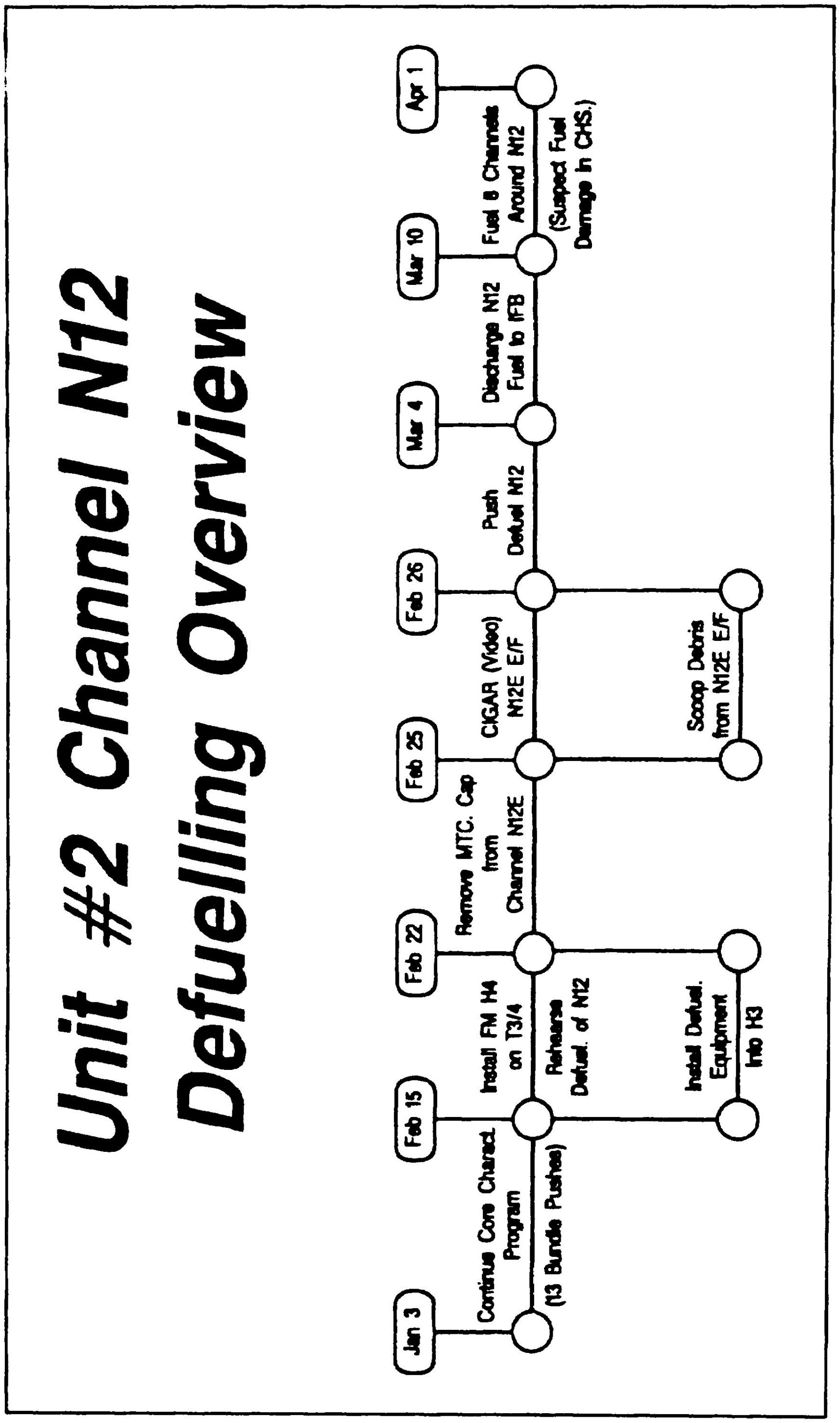


Figure 5

N12 Defuelling Overview

the water draining from N12E to minimize the spread of contamination especially onto the FM trolley below N12E.

On February 22, 1992 the maintenance cap was removed from N12E and the collection trough placed into position to collect the D2O from N12E while the maintenance platform was being removed from the bridge. The shielded mini-platform was removed from the East FM bridge and the East Fuelling machine (Head #4) was raised into position to lock onto N12E. Just prior to homing and locking Head #4, the collection trough was removed from N12E. The fuelling machine was then advanced and locked onto N12E to stop the D_2O leak. This work of removing the maintenance cap, installing and removing the collection trough and homing and locking the fuelling machine onto N12E was completed in approximately 12 hours.

The next step of the program was to remove loose debris from the endfitting by using a debris scoop.

See Figure 6. Picture of Debris Scoop

This scoop was advanced down the endfitting until it stalled. This stall location was determined to be the start of the flowholes in the liner.

The debris scoop was then removed from the channel and the 4 lug closure was inserted to close up the channel. A leak check was performed on the 4 lug closure before the fuelling machine was removed from the channel. There was no leakage from the channel. This was visually confirmed later when the fuelling machine was removed from the channel.

The channel was then CIGAR videoed to assess the amount of debris left in the endfitting and to determine the condition of bundle # 1 at the latch.

See Figure 7. Picture of N12E before shear scooping.

The CIGAR picture showed that there were fuel elements from bundle # 1 in the channel stuck crossways in the flowholes of the liner. Part of bundle # 1 was visible behind the debris.

The shear scoop was then advanced through the endfitting in an attempt to shear off the fuel fragments that were stuck in the flowholes. After several attempts, this shear scoop was eventually advanced to the latch.

See Figure 8. CIGAR video after shear scoop advanced.

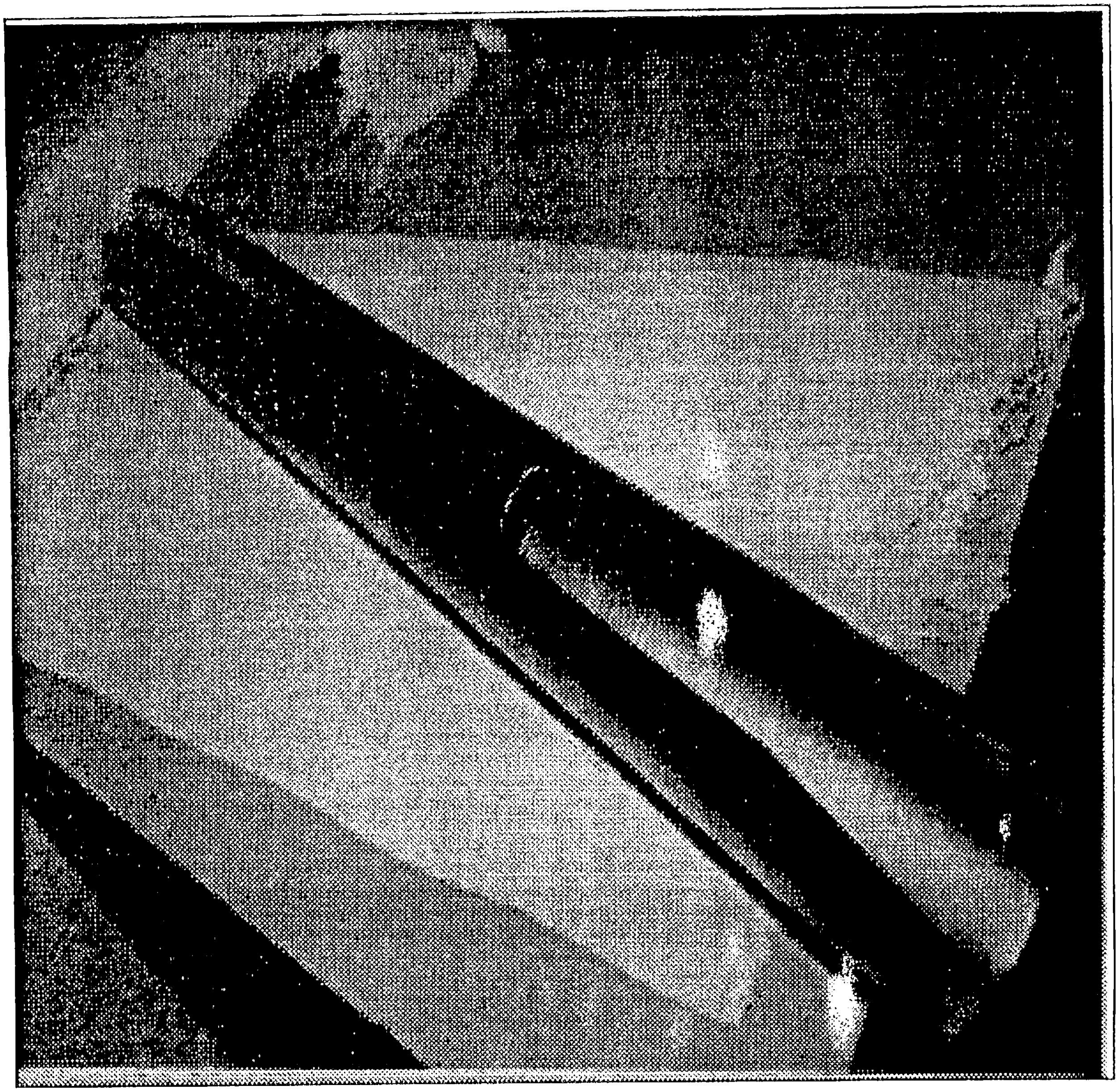


Figure 6

Debris Scoop

Figure 7

N12E Before Shear Scooping

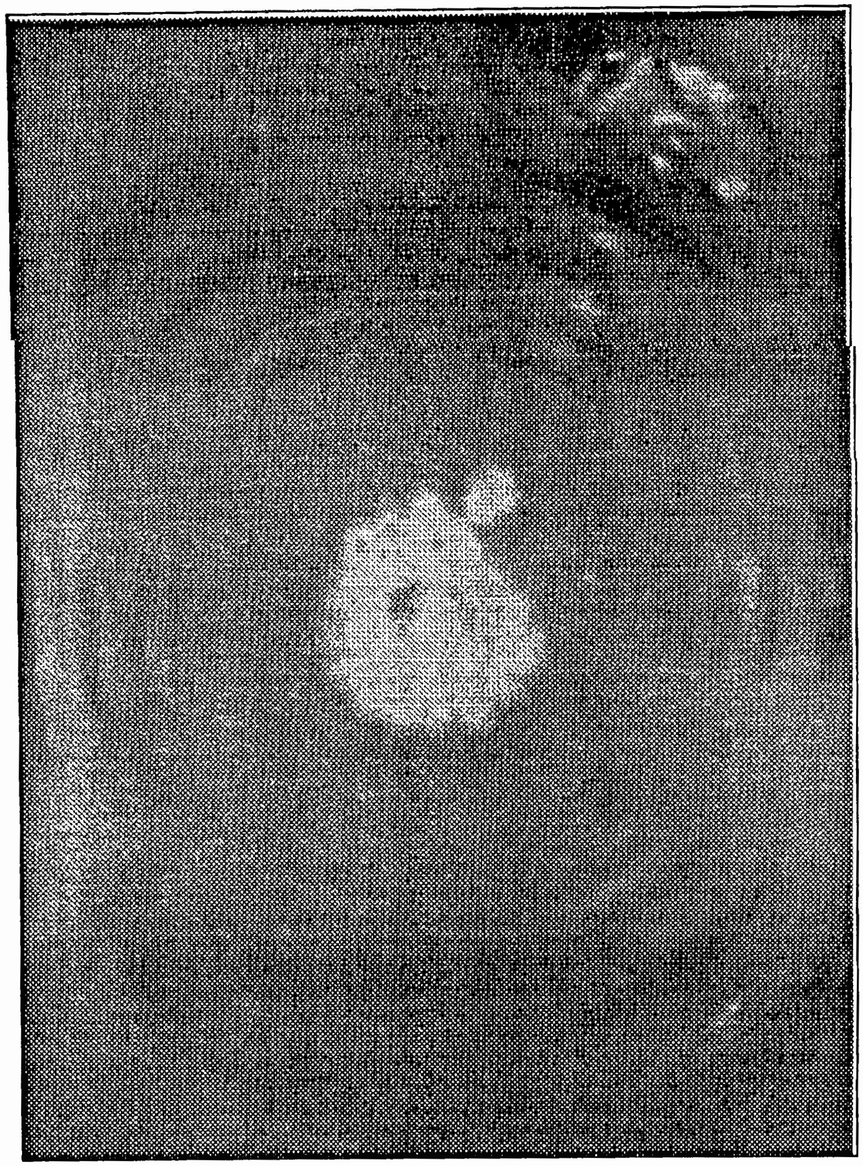


Figure 8

CIGAR video after shear scoop advanced

The channel was again CIGAR videoed to assess the state of bundle # 1 and the fuel debris remaining in the flowhole area. The CIGAR picture showed that the fuel debris was removed from the flowhole area but debris still remained in the holes. Bundle # 1 appeared to be intact but the centre seven elements were missing and there appeared to be a small pile of debris still at the front of the bundle. It was decided to try to advance a defuelling scoop to push bundle # 1 away from the latch and attempt to open the latch. After three attempts, the latch was successfully opened (i.e. the defuelling scoop had advanced the full distance).

See Figure 9-A . Picture of Defuelling Scoop

The opposite fuelling machine (upstream end) was loaded with grapple extensions to push the fuel out of the channel into head #4 (the downstream fuelling machine).

See Figure 9-B. Picture of grapple extension with push plate.

The grapple extensions are normally used with the grapple heads to pull fuel bundles out of the channel. It was decided to try to push the bundles out of the channel because of the damaged state of bundle # 1 and possibly other bundles in the channel.

The push defuelling operation was started on March 3, 1992. The defuelling of channel N12 was completed in approximately 8 hours. The damaged fuel was then pushed into the reception bay where the fuel was subsequently examined for damage.

See Figure 10-A and 10-B. Pictures of bundle # 1 from 2N12 (downstream and upstream ends)

After the fuel was discharged into the reception bay, fuelling machine head #4 was decontaminated and test operated on the calibration port. The magazine positions in head #4 were also visually inspected for remaining fuel debris and confirmed acceptable for service, trolley 3/4 returned to unit 2 to defuel the remaining 8 channels around N12 that could not previously be fuelled because of the maintenance cap restriction.

Fuelling machine head #4 operated satisfactorily for the fuelling operations on N12 and surrounding 8 channels. This head was removed from service and is presently being decontaminated and rebuilt as a spare fuelling machine head.

COMPLETION OF U2 RETURN TO SERVICE PROGRAM

The remaining parts of the unit 2 return to service program are as follows:

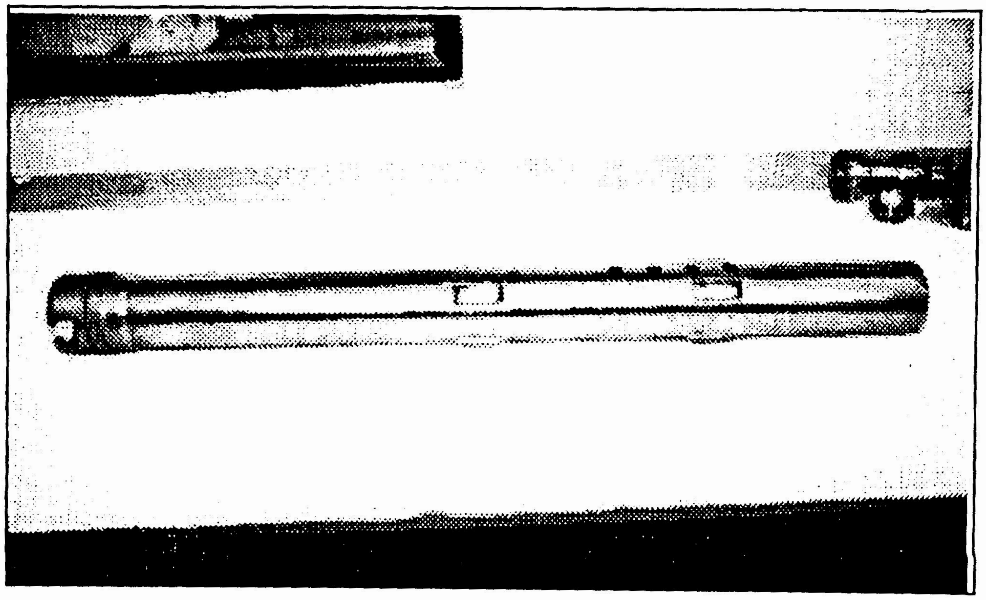


Figure 9-A
Defuelling Scoop

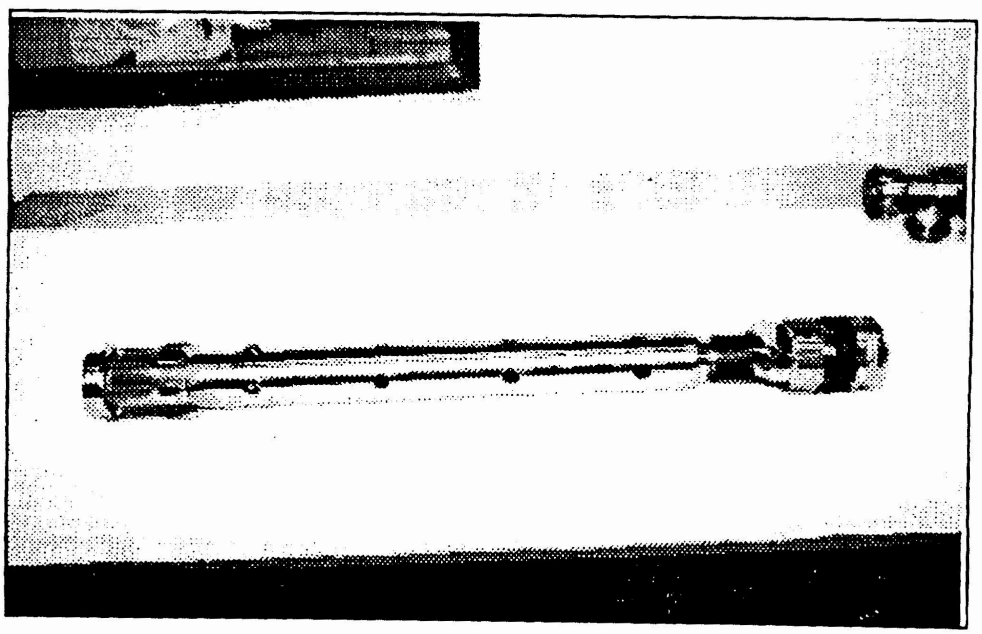


Figure 9-B
Grapple Extension with Push Plate

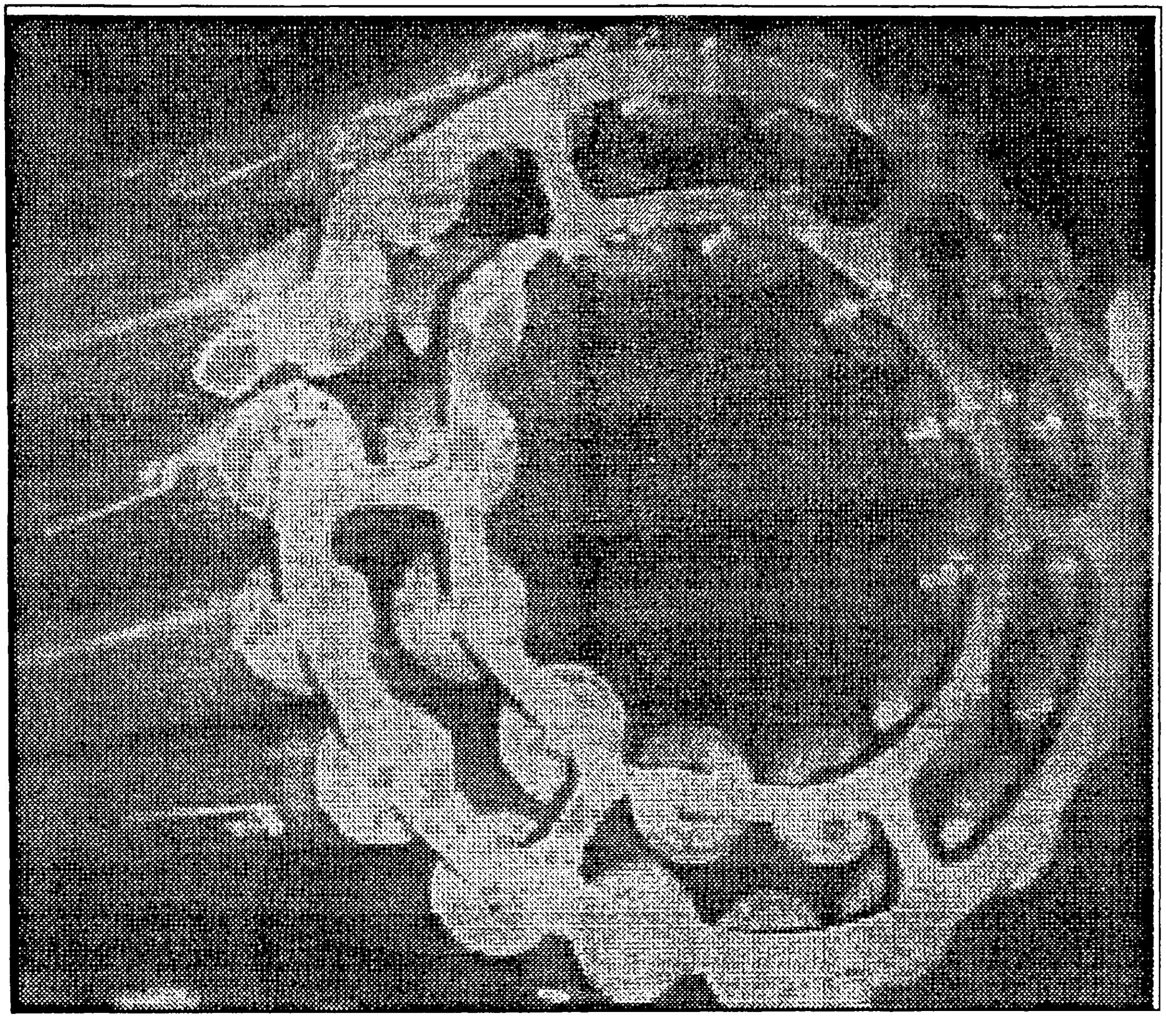


Figure 10-A

Bundle #1 from 2N12 (Downstream end)

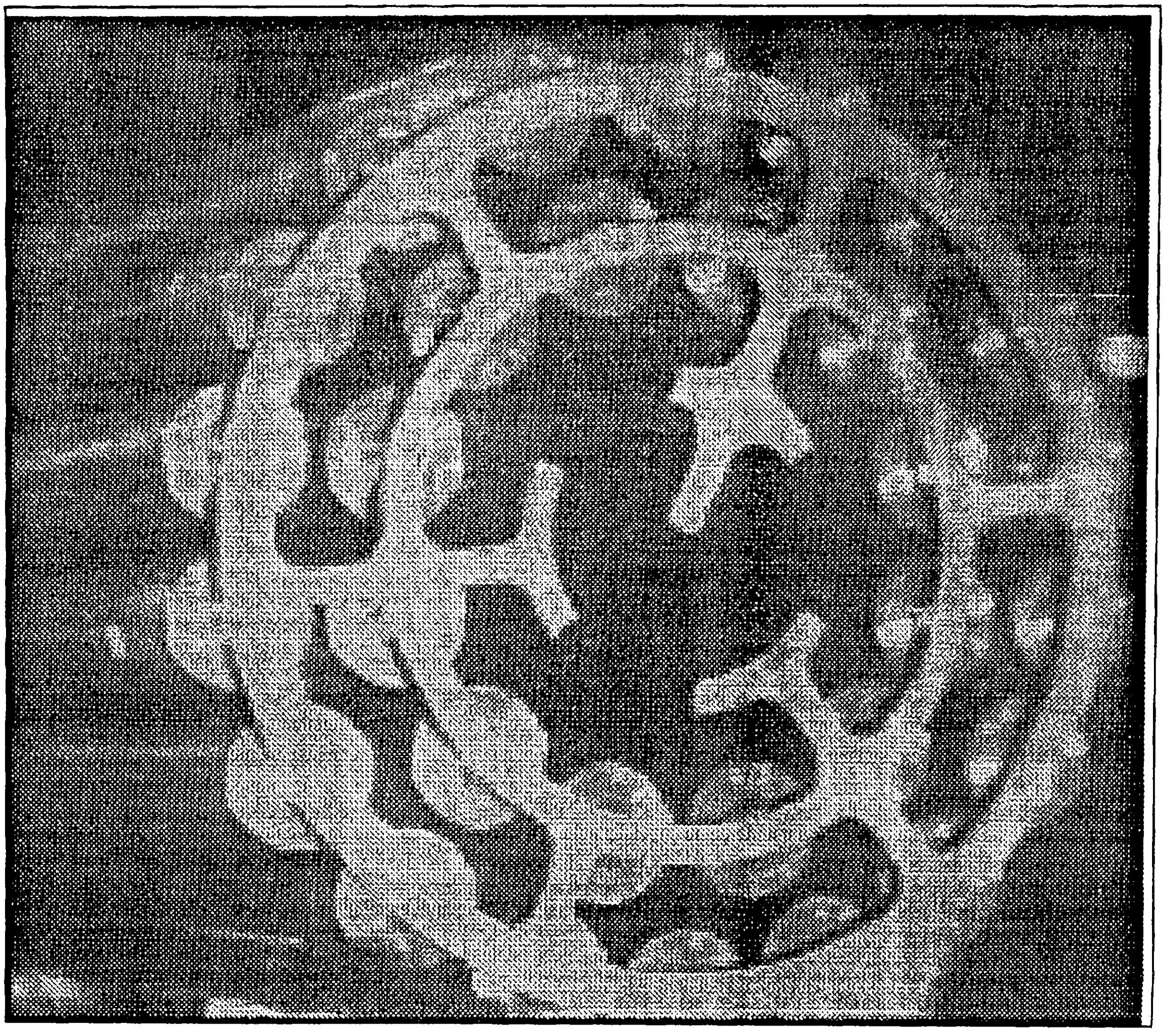


Figure 10-B

Bundle #1 from 2N12 (Upstream end)

1) Core characterization has been completed, with over 400 fuel bundles from 107 channels having been inspected. Severe damage has been found to be limited to columns 12 & 13. Only minor damage has been found elsewhere.

2) Full and partial CIGAR of 19 channels is complete. Only channel K13 (already replaced) and K12 (dispositioned) have been found to have significant PT wear.

3) Plans are in place to replace N12 due to debris trapped in the end fitting liner. No other channels require replacement at this time.

4) Complete reactivity fuelling.

5) Install 7 vane impellers in PHT pumps.

6) Install new turbine generator rotor.

7) Complete inspection programs on other unit 2 equipment (i.e. steam generators, Reactor Feeders etc.).

8) Complete outstanding work on approximately 40 major ECNs (ie, moderator level instrumentation, interunit feedwater tie) and remaining - approximately 150 minor ECNs.

See Figure 11. D2 Return to Power Schedule.

The remainder of this program is estimated to be completed by September 18, 1992. At that time, Unit 2 should be safely returned to 100% full power operation.

Throughout the entire N12 investigation and unit 2 return to service program, the fuel handling systems and staff have been called upon to perform work that had never been included in the original commissioning program, especially that early in the station's life. This demand has necessitated a great deal of resourcefulness and commitment from the fuel handling operators and technical support staff to overcome a large number of challenges. The experience and knowledge gained by this ambitious fuel investigation and restart program will benefit both Darlington and other CANDU stations in gaining a better understanding of fuel, pressure tube, and PHT system performance.

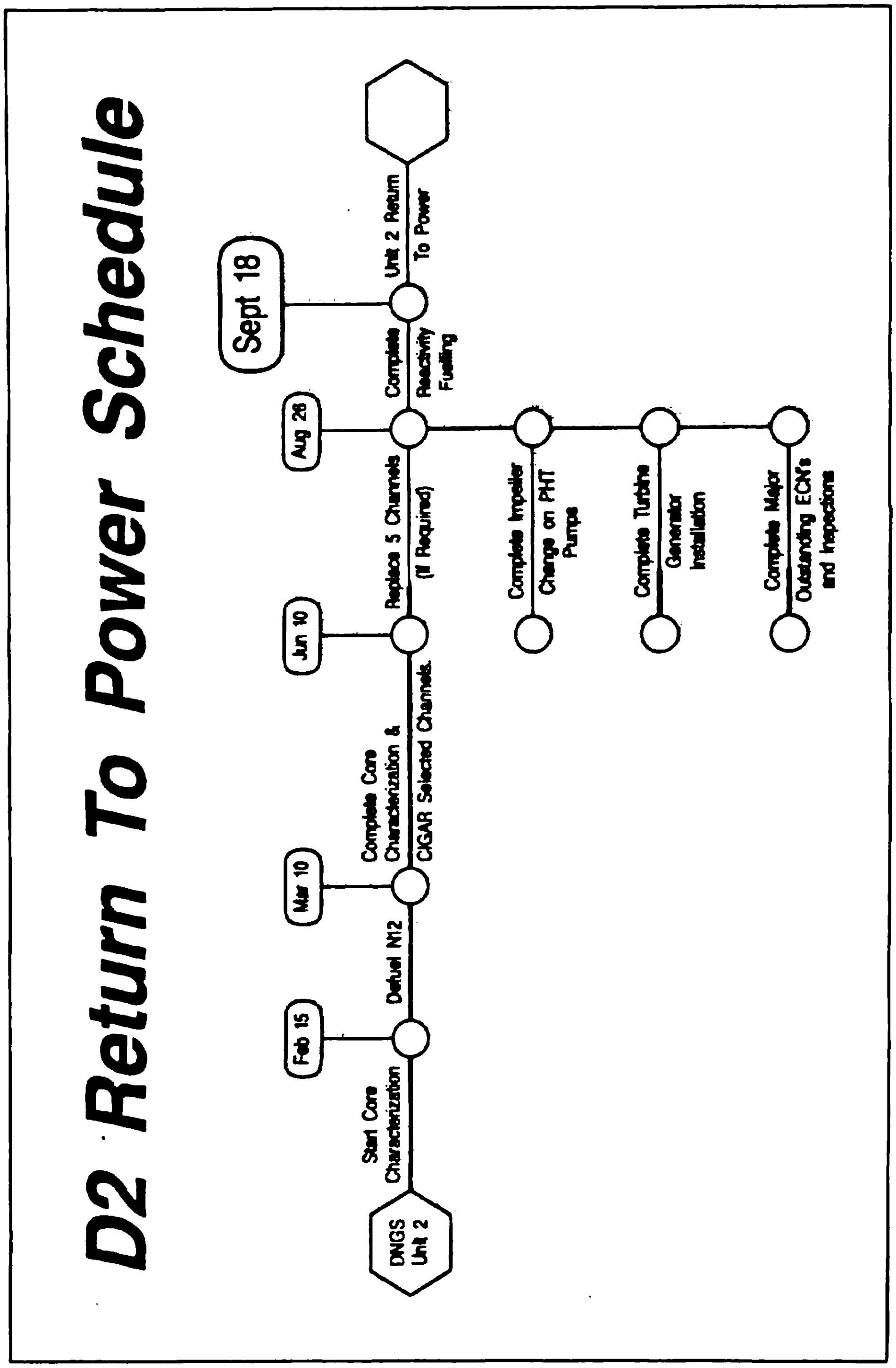


Figure 11

D2 Return to Power Schedule