REMOTE AUTOMATED TOOLING FOR CANDU REACTOR CORE INSPECTION

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ABSTRACT

An automated inspection tool has been built for use inside the core of a CANDU reactor. It is capable of cleaning, bore gauging, and viewing via CCTV the various rolled joint areas. The tool will be used initially during the early retubing of Pickering Units 1 and 2.

INTRODUCTION

Radiation induced creep has resulted in elongation and sagging of the fuel channels in Ontario Hydro's Pickering 'A' nuclear generating station. Because of this, the fuel channels will be replaced in the near future. The Pickering fuel channel is described in the Appendix.

Atomic Energy of Canada, Canadian General Electric and Spar Aerospace have worked together with Ontario Hydro to design a system to achieve this objective. In this paper we describe one of several remotely operated tools designed, fabricated and developed at Chalk River Nuclear Laboratories for fuel channel inspection.

IN-CORE INSPECTION REQUIREMENTS

During the replacement of pressure tubes or calandria tubes in a CANDU reactor there are several occasions when inspections of various kinds must be performed. For the current early retubing of Pickering units 1 and 2 these inspections include:

(a) visual inspection of the existing calandria tube to tubesheet rolled joints;

(b) visual inspection, cleaning and bore measurement of the end fitting in the rolled joint area prior to insertion of the new pressure tube, and;

(c) visual inspection cleaning and bore measurement in the pressure tube to end fitting rolled joint area after rolling.

To accomplish these various tasks, inspection tools must enter the reactor via the end fitting which is 2.6m long and approximately 10cm internal diameter.

DESIGN OF THE INSPECTION TOOL

Since, typically, visual inspection, cleaning and bore gauging operations follow each other in the inspection sequence, a single tool was built capable of performing all three functions. The main components of the tool are the tool heads, the drive system and the control system. These components are mounted in a frame which precisely locates the tool with respect to the end fitting centreline (Figure 1). The main components of the tool are described in greater detail below. Figures 2 and 3 show the arrangement of the tool heads.

THE VISUAL INSPECTION HEAD

The visual inspection head (Figure 4) is based on a standard Westinghouse ETV-1250 camera with 50mm lens and a custom made right angle viewing attachment which contains an array of lights. The attachment is designed for easy replacement in the event of light bulb failures. The camera is lead shielded and air cooled to extend the camera life in the radiation field.

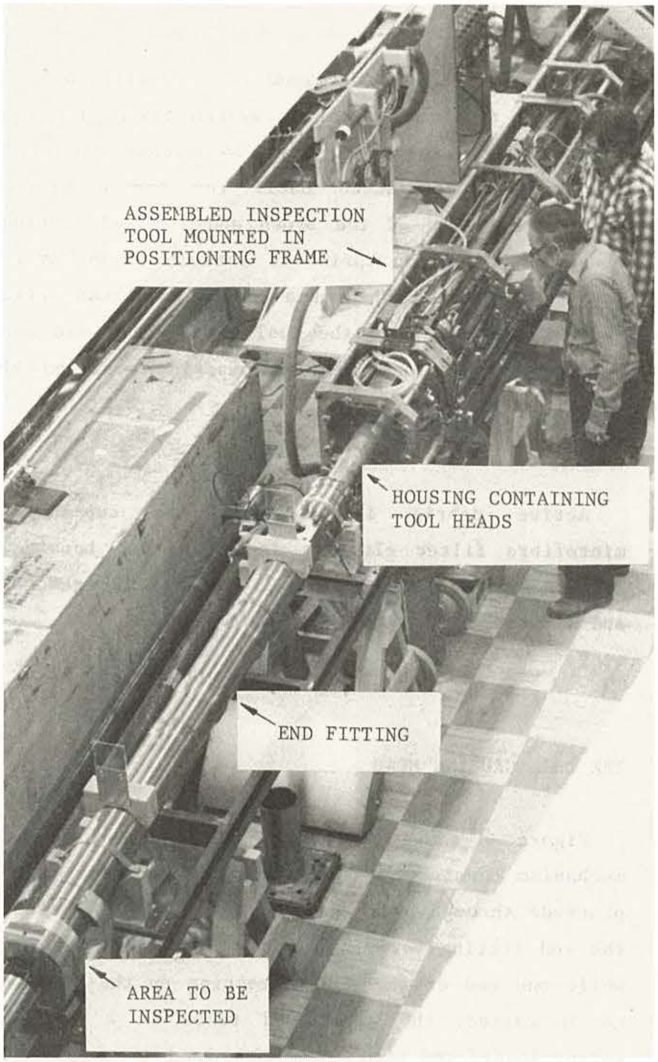

FIGURE 1: GENERAL VIEW SHOWING COMPLETE TOOL

Once the camera is positioned axially, the tool is rotated to view the rolled joint surfaces. The view obtained by the camera is monitored remotely by an operator. The operator is able to switch from automatic to manual operating mode and control the light level, light direction, camera focus and direction of tool rotation. The tool may be repositioned axially and rotationally to view an area of particular interest. TV image evaluation is the responsibility of the operator.

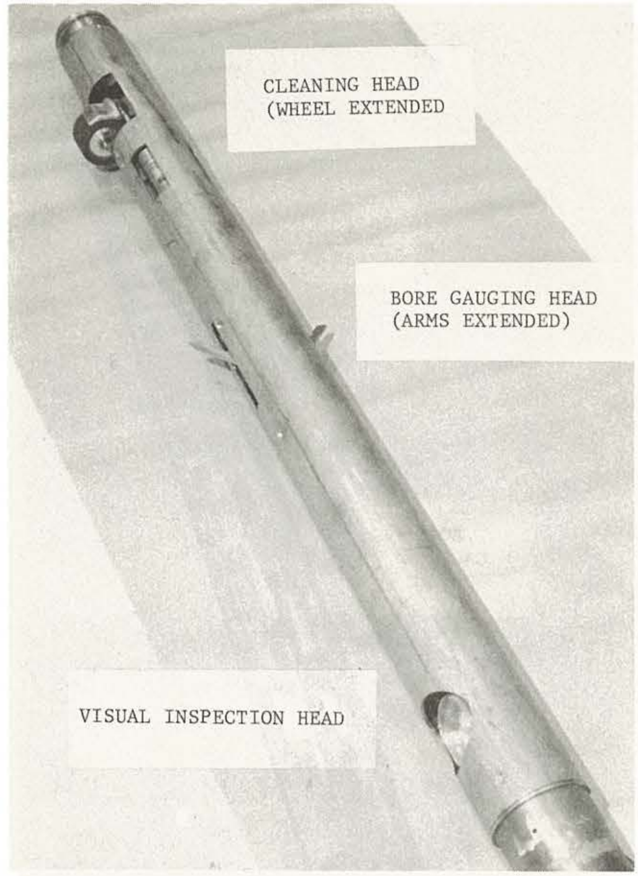

FIGURE 2: ARRANGEMENT OF THE TOOL HEADS

THE CLEANING HEAD

Figure 5 shows the cleaning head. The cleaning wheel is approximately 6 cm diameter and 4 cm wide, and is composed of a phenolic fibrous matting imbedded with aluminum oxide. The wheel is easily removable from the head and is driven by a DC motor and chain drive through a separable coupling.

The cleaning wheel drive mechanism and its associated support structure is raised as a unit through the tool body to the surface to be cleaned. The drive is provided by a DC motor via a worm and wheel mechanism which rotates a leadscrew. A rectangular shaft, parallel to the leadscrew, guides the brush drive mechanism as it is raised or lowered.

When the cleaning wheel contacts the surface to be cleaned, the contact force causes the brush drive mechanism to pivot about a pin and close a limit switch. This switch closure causes the vertical

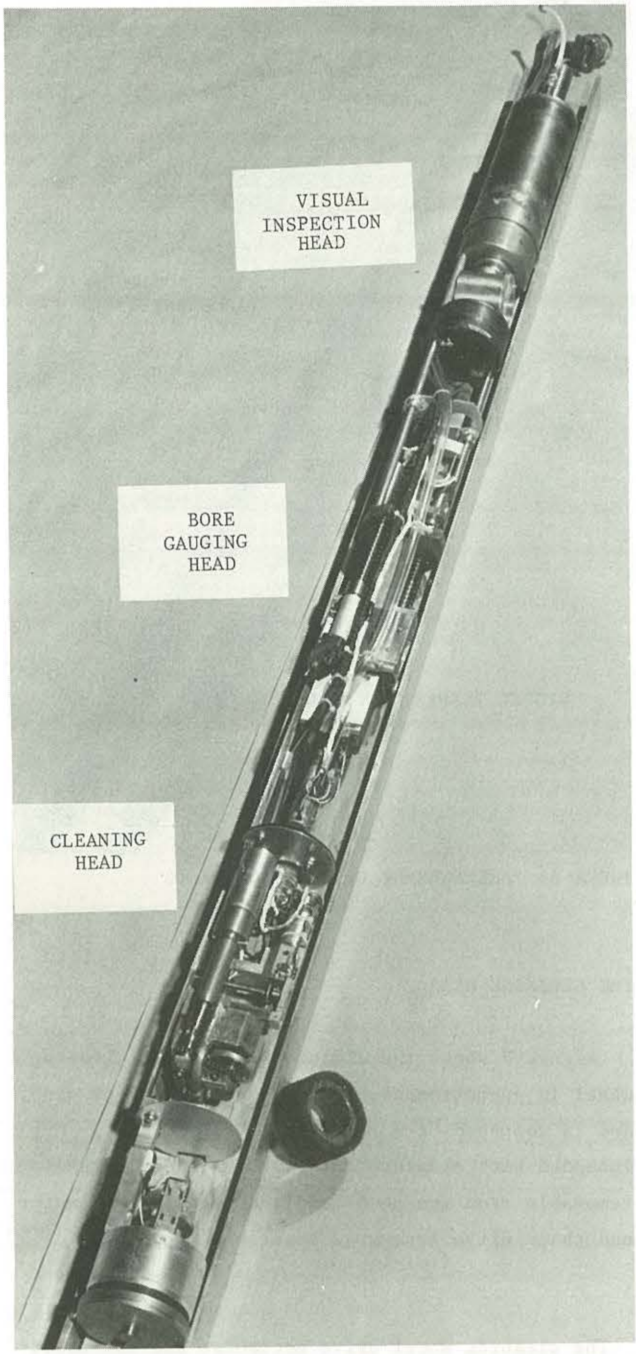

FIGURE 3: ARRANGEMENT OF THE TOOL HEADS (HOUSING REMOVED)

drive to stop raising the cleaning wheel. The cleaning head is then rotated through 360° at 2 rpm whilst the cleaning wheel is being driven. Debris released by the cleaning pad is collected by a vacuum system and routed to a shielded filter. The operation finishes with the cleaning head at the bottom of the cleaned diameter. When the cleaning operation is complete, the brush is retracted. Closure of a limit switch signals that retraction is complete.

The head has been designed to be retrievable in the event that the elevating system fails with the wheel in the raised position. To release the head, the tool is retracted until the contact force between the side of the brush and the end fitting causes an extension spring to deflect to an "over-centre" position. When this occurs the brush drive mechanism pivots into the tool body. The head can be quickly put back into its working position by manual intervention.

Active debris is collected in cup-shaped microfibre filter elements in a shielded housing. The housing is removed manually for filter removal and disposal in a remote facility.

THE BORE GAUGING HEAD

Figure 6 shows the bore gauging head. The mechanism consists of two spring loaded arms which protrude through slots in the tool body to contact the end fitting bore. Each arm is pivoted so that while one end of the arm is resting on the surface to be gauged, the other end rests on a central spring loaded rod with a pivoting head to compensate for misalignment. The rod is coupled to a pair of LVDT cores. The mating LVDT coils are rigidly mounted to the tool body. Deflections from the LVDTs are used to calculate the end fitting diameters contacted by the arms.

The LVDTs are shielded against the changing magnetic permeability of their working environment and are calibrated for temperature effects. A thermocouple monitors the temperature of the LVDTs and a connection is made to their readings by the microprocessor before they are relayed.

The diameter variation in the Z direction (i.e. along the centerline of the end fitting) is monitored by withdrawing the tool and allowing the arms to follow the end fitting contour. Data is

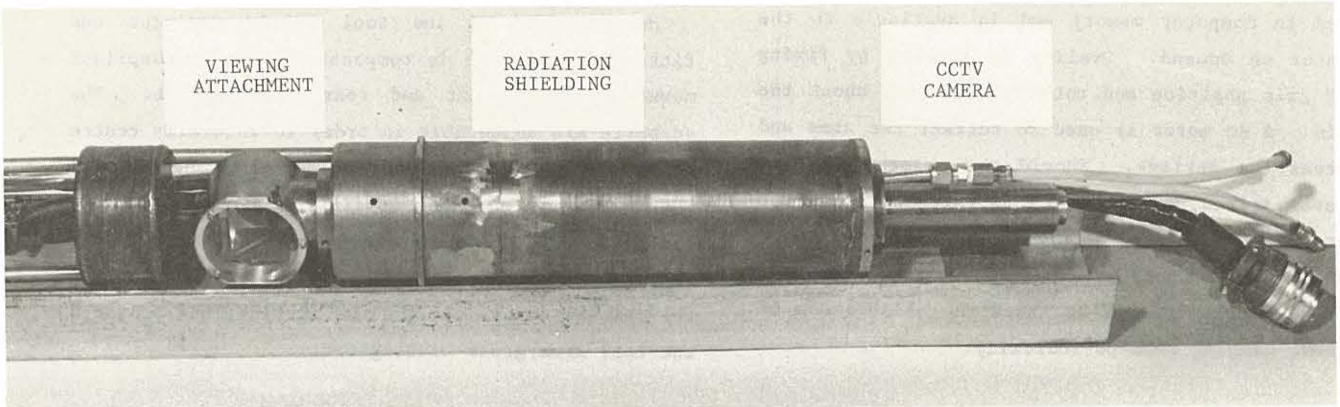

FIGURE 4: VISUAL INSPECTION HEAD

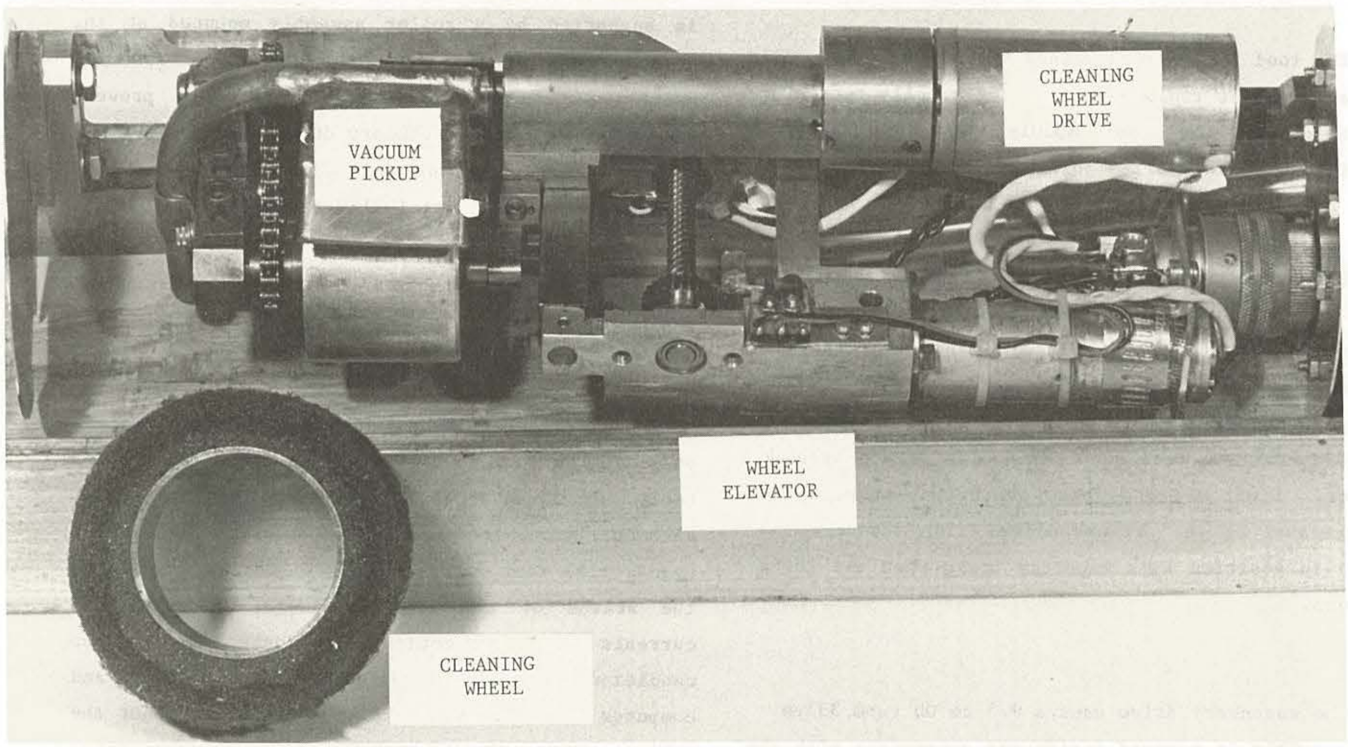

FIGURE 5: CLEANING HEAD

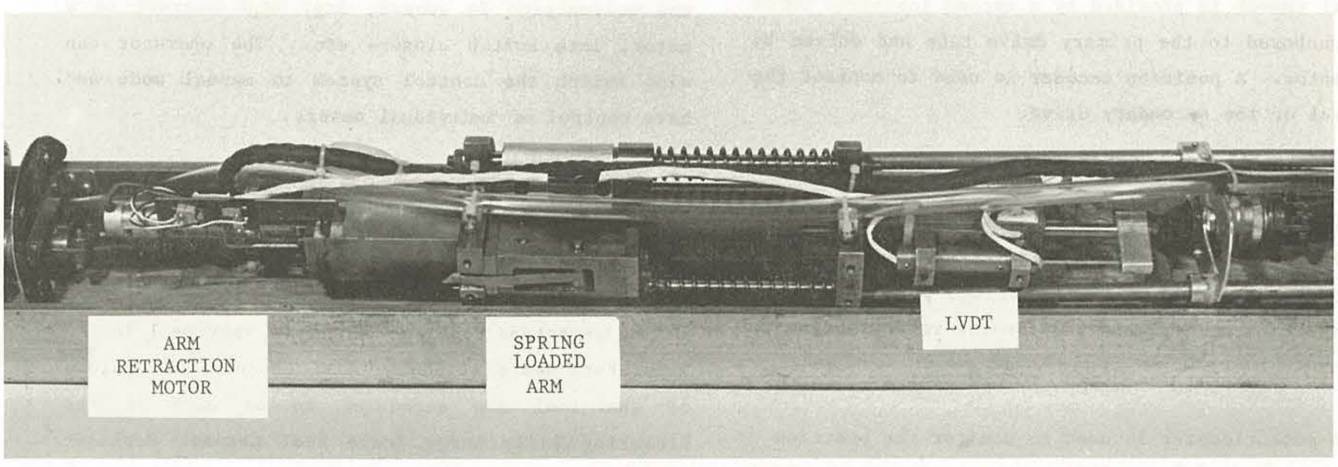

FIGURE 6: BORE GAUGING HEAD

stored in computer memory and is available to the operator on demand. Ovality is checked by fixing the Z axis position and rotating the tool about the Z axis. A dc motor is used to retract the arms and compress the springs. Should the motor fail with the arms raised, the tool may be retracted from the reactor but will not be capable of being advanced further. A calibration tube mounted at the front of the tool module is used to check the calibration of the bore gauging head periodically.

Misalignment of the tool module and the end fitting centre line is compensated for by compliant mounts at the front and rear of the tool. The supports are adjustable in order to initially centre the tool in the module but allow compliance if the module is not on the end fitting centre line. A spring loaded nose cone equipped with microswitches is attached to the front of the tool. It aids in the initial entry into the end fitting, and protects the tool from gross misalignment.

THE DRIVE SYSTEM

The tool is provided with a two stage drive system to advance the tool heads from their fully retracted position in the tool module to their working positions at the rolled joint.

The primary drive uses a 10cm OD tube, 365cm long. The rear of the tube is mounted on a bracket which in turn is supported by a pair of linear bearings and roundways mounted in the tool module. Nylon bearings support the primary drive tube as it is advanced by a leadscrew and ball nut combination driven by a dc motor. Limit switches plus overtravel stops limit the travel of the primary drive. The leadscrew is held in position by a magnetic brake when not being driven.

The secondary drive uses a 9.5 cm OD tube 335cm long. This is mounted inside and concentric with the primary drive tube and contains the tool heads. The axial travel is provided by a second leadscrew which is anchored to the primary drive tube and driven by dc motor. A position encoder is used to monitor the travel of the secondary drive.

The primary and secondary drive tubes are keyed together so that they may be rotated as one unit. A spur gear attached to the OD of the primary tube is driven by a dc motor to provide the rotary motion.

A potentiometer is used to monitor the position of the rotary drive. This rotary motion is required for cleaning, inspection and bore gauging.

Hoses and electrical wiring for the heads are attached to the head support tube and the cable loop is supported by a roller assembly mounted at the outboard end of the module. The roller assembly maintains a tensile load on the cables to prevent excessive sag. The secondary drives are powered via a zero force connector which is engaged when the primary drive is at its full Z extension.

THE CONTROL SYSTEM

A microprocessor-based control system is mounted on board the tool to control and monitor the various tool functions. When operating in its fully automatic mode, it controls the complete sequence of events from tool entry to tool withdrawal, monitors the status of all limit switches and the load currents of all the motors. The control system also conditions the output signals from the LVDTs and computes the various bore diameters. Throughout the tool operation the controller will generate status messages to the operator and will stop the tool if the malfunction is sensed, e.g. high current on a motor, late switch closure etc. The operator can also switch the control system to manual mode and have control of individual motors.

CONCLUSION

The prototype tool has performed very well in laboratory tests at CRNL. Five production versions of the tool are scheduled to be used in the Pickering Early Large Scale Fuel Channel Replacement Program in 1985.

APPENDIX

OUTLINE OF THE CANDU REACTOR FUEL CHANNEL [1]

One of the main engineering characteristics of the CANDU nuclear power reactor is the use of pressure tubes, rather than one large pressure vessel, to contain the fuel and coolant. The power reactor basically consists of a calandria, which is a large tank containing the heavy water moderator, end shields, and an array of identical fuel channels which project through the end shields and calandria. Figure 7 is a simplified schematic. The principal components of a fuel channel are the pressure tube, the calandria tube, the central spacers and the end fittings as shown in Figure 8. The end fittings are of 403 stainless steel; the pressure and calandria tubes are of zirconium alloys.

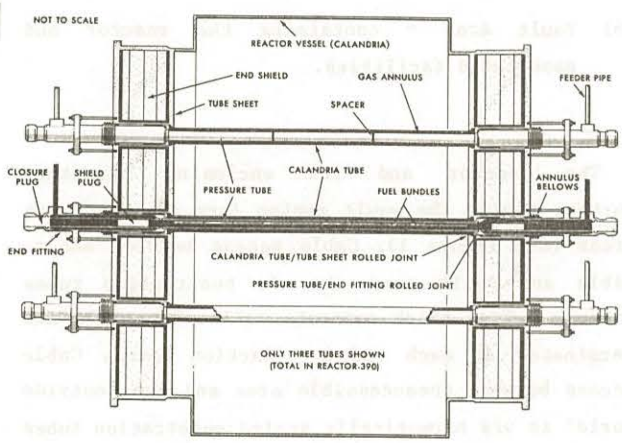

FIGURE 7: SIMPLIFIED DIAGRAM OF PICKERING REACTOR

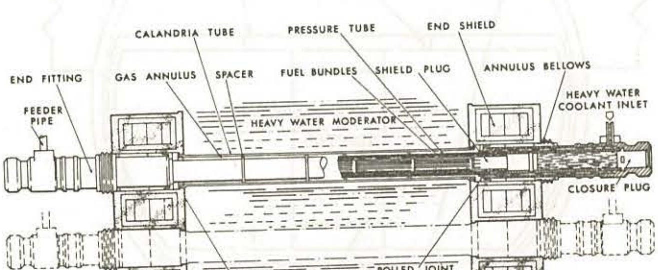

FIGURE 8: SCHEMATIC OF A FUEL CHANNEL

The pressure tubes of about 6 m (240 in.) length, 4.1 mm (0.162 in.) wall thickness, and 103 mm (4.07 in.) inside diameter, contain the fuel and heavy water coolant at a pressure of 9.6 MPa (1400 psi) and a temperature of 293°C (566 K). The pressure tubes are horizontal and are rigidly joined to end-fittings which are firmly supported by the end shields. The calandria tubes are concentric to the pressure tubes and separate the cool moderator (about 65°C) in the calandria from the hot pressure tubes.

Three grooves are machined in the end-fitting bore (Figure 9). The pressure tube is inserted to cover the grooves, and the tube is roll-expanded into the grooves. The rolling reduces the wall thickness by 12 to 14% and the grooves are partially filled with tube material. The material in the grooves tends to lock the tube to the end fitting producing very good leak tightness and axial strength. Similarily, the calandria tube is roll-expanded into a groove in the calandria tubesheet.

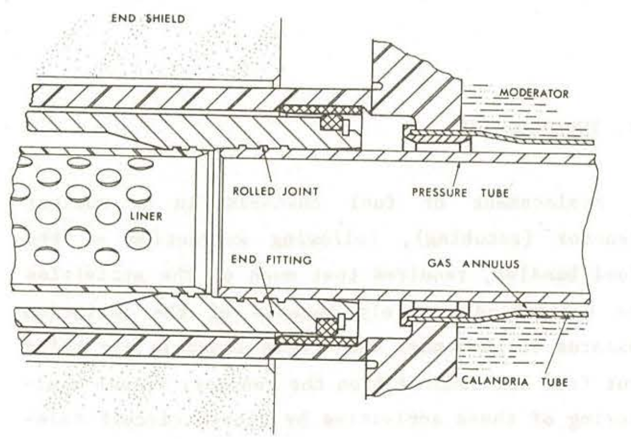

FIGURE 9: ROLLED JOINT ARRANGEMENT IN PICKERING REACTOR

Reference

[1] P.A. Ross-Ross "Pressure Tubes: The Pressure Vessels in the CANDU Nuclear Power Reactor", Transactions of the CSME, Vol. 5, No. 2, 1978-79, p. 61-68.