

RTD PROBLEMS AT DARLINGTON

D. McAllindon

AECL-Ontario Hydro Services
Darlington NGD, PO Box 4000
Bowmanville, ON, Canada
L1E 1R6

D. Sloan

Ontario Hydro Nuclear
Darlington NGD, PO Box 4000
Bowmanville, ON, Canada
L1E 1R6

P. Mayer

Ontario Hydro Technologies
800 Kipling Av
Toronto, ON, Canada
M8Z 5S4

Abstract

Resistance Temperature Detectors (RTDs) and their measurement circuit components have been a significant maintenance item at Darlington. Analysis of the problems has shown that RTDs and electrical penetrations (EPs) have been the largest sources of faults. A failure mechanism in which the RTD electrical resistance shifts upward was identified as a major source of RTD failures, which prompted a detailed failure investigation by Ontario Hydro Technologies (OHT). The investigation concluded that the root cause failure mechanism is chlorine contamination of the platinum wire during manufacture which resulted in surface damage to the wire and flaking of the wire surface during operation. Electrical penetrations in Darlington are of a pre-built modular design with two crimps internal to the EP. Spurious resistance in poor quality crimps in the EPs lead to errors in resistance measurement. The problem led to a complex and costly job to insert new modules in existing spare EPs.

1. Introduction

A Resistance Temperature Detector (RTD) is a temperature measuring device that consists of a thin (0.001" diameter) platinum wire with its length manufactured to have a precise electrical resistance (Figure 1 showing schematic of rtd). As the temperature of the platinum wire changes, its resistance responds in a predictable manner.

In each unit at Darlington, there are 480 RTDs in the Channel Temperature Monitoring (CTM) System (one for each fuel channel), and 188 RTDs in the Channel Power Measurement (CPM) System for a total of 668 RTDs per unit. CTM RTDs are placed in outlet feeders and used to confirm flow in each channel while CPM RTDs are used to measure the temperature increase across a fuel channel as a part of thermal power measurement. CPM RTDs are connected at the inlet and outlet feeders of a fuel channel.

Lead wires running from the platinum wire to measurement electronics have resistance that, if not accounted for, can severely affect the accuracy of the measurement. In order to compensate for the resistance of the lead wires, a third wire is soldered to one end of the platinum wire (Figure 1 A). Then the lead-wire resistance can be measured (resistance between the two wires on the same end of the platinum wire, A and B) and subtracted from the measured resistance (B to C) to give the true platinum wire resistance.

Other elements in the RTD measurement circuit are shown in Figure 2. An RTD is connected to a cable that runs to an electrical penetration (EP) where the cable is spliced to wires going through the EP. The EP wires are spliced again outside the EP to a cable that runs to the electrical measurement circuit that transforms the resistance into a voltage. CTM RTDs are measured using a resistor bridge. The voltage goes into an analog input (AI) card and from there into both the Digital Control Computers (DCCs). CPM RTDs go into a differential amplifier for transformation to a voltage. From there, the voltage signal goes to two separate AIs in the control room, one for each DCC.

Problems can occur in any of the circuit elements and the key to solving problems is troubleshooting. A consistent troubleshooting procedure has been developed at Darlington that diagnoses and resolves the source of problems.

A review of all the problems encountered to date in Darlington has shown that RTDs, EPs, and connectors are the main sources of our RTD problems.

RTDs have been a significant maintenance item at Darlington. The technical specification for the RTDs specifies a failure rate less than 5×10^{-3} failures/year, or about 3 failures per year per unit. However, for

example, during the station outage in 1997, 59 RTDs were replaced and in a poison outage on unit 3 early in 1997, another 24 RTDs were replaced.

Another significant problem is electrical penetrations. Darlington uses a pre-built style of EP that has two crimps inside the penetration. We believe, based on outside findings[1], that the crimps have degraded and led to increased resistance in some circuits that, though small, has a serious impact on the RTD loop accuracy. This problem has so far been found in units 1, 2, and 3, with most of the problems in a specific module in unit 2. Three new penetration modules were installed in unit 2 during the 1997 station outage.

RTD connectors have also been a problem and 6 connectors were replaced during the last outage. The next area to get attention after RTDs and EPs will be connectors.

In this report, the particular type of RTD failure causing the large failure rates and the EP replacement program will be discussed. To begin, however, it is important to understand the troubleshooting process.

2. Troubleshooting

Our first step in troubleshooting is to measure the resistances across the different pairs of RTD wires from the control distribution frame (CDF). (Refer to Figure 1) A form has been developed for control maintenance techs to record resistance measurements between all legs of the RTDs. If the resistance across the RTD (A to C, B to C) are not equal (within 0.2 ohms), we know there is a problem with wiring, although this may be in the RTD itself, the connector, splices, or the penetration. If the measurements are equal, we can determine the temperature by reference to a chart of RTD resistances versus temperature. If the temperature reading does not agree (within some uncertainty) with the computer reading, then a problem with the electrical measurement card or AI card is suspected.

If the problem is in wiring, further troubleshooting must wait until an outage. Connections in the circuit are opened and measurements are taken looking both ways from the connection. For example, the first step is to disconnect the rtd and measure across its leads. Also, the connector is shorted and measurements are taken from the CDF of the wire resistances. In this almost binary troubleshooting process, the source of the problem is tracked down with certainty.

Until a systematic troubleshooting procedure was put in place, problems with the EPs were very difficult to resolve. The standard practice was to replace components until the problem went away. Also, EPs were not recognized as a potential source of problems. Now, opening the splices on each side of the penetration and measuring the resistance of wires across the penetration is the final step in troubleshooting.

3. RTD Failures

While the normal failure mechanisms for RTDs are open or short circuits, a different type of failure mechanism in which the rtd reads high (3 °C or more) has caused most of the failures in Darlington. According to work management system, in the history of Darlington, 253 RTDs have been replaced, of which 109 have been suffering from this type of failure (others have been replaced as part of the "replace and see if it fixed the problem" school of troubleshooting).

Typically, the fault is detected in one of the following ways:

1. An RTD is reading higher than the saturation temperature (boiling point at the heat transport loop pressure), or
2. An RTD is causing spread alarms (an RTD reads higher or lower than surrounding RTDs), or
3. An RTD is reading high during zero-power hot biasing.

We can now easily spot this type of failure during on-line troubleshooting. If the RTD is reading high and two resistance measurements (A to C and B to C) are equal and agree with the computer reading, then we immediately suspect an RTD "calibration shift" problem.

Calibration checks of these RTDs have shown that there is an increased resistance throughout the whole range of operation, though the increased resistance is not constant over the whole range.

An overwhelming number of the failures have occurred in unit 3 and in a distinct serial number range, corresponding in general to a time of production of the RTDs.

Another clue is that only RTDs on outlet feeders have failed in this way. Temperature is the major difference between the inlet feeders and outlet feeders

environment; therefore, temperature is thought to play a significant role in the failure. An industry study on aging reported that RTDs in continuous operation at 320 °C for 18 months drifted to levels comparable to those in Darlington [2].

Because of the large numbers of this type of failure, Darlington decided to sponsor a failure investigation of these RTDs. Ontario Hydro Technologies was contracted to do the failure analysis [3]. (The manufacturer was also sent a sample of failed RTDs to examine.)

OHT took some scanning electron microscope pictures of the platinum wire of the RTD elements. (Refer to Figures 3 and 4 - pictures of unfailed and failed RTDs) The normal, unfailed RTDs have platinum wire with a smooth surface (Figure 3). The failed RTDs have platinum wires with a damaged surface that shows flakes peeling off the surface (Figure 4). The increased resistance of these damaged wires is thought to come from the loss of cross-section caused by the flaking.

What would cause this kind of damage to the RTD surface? Initially, oxidation was suspected, but a literature search revealed no evidence for oxidation at the conditions to which the RTDs are exposed. The current theory is that chlorine present on the surface of the platinum wire during manufacturing could have caused damage to the platinum surface. During operation, thermal stresses cause flakes to peel off the surface and reduce the effective current-carrying diameter of the wire. Only a 1% reduction in diameter is required to cause the resistance to increase to the extent observed. The process may take years of operation before an RTD resistance increase is noticed. (Note: we don't really know whether the problems show up suddenly or only gradually. Bias measurements of RTDs during low power hot conditions are the only way to really tell and they are not done very often.)

A meeting was to take place between the manufacturer, OHT, and Darlington NGS to discuss the findings but results were unavailable at the time of publishing.

4. Penetrations

Electrical penetrations are used to carry electrical signals from inside the reactor vault to the outside world while still providing the required containment barrier.

The electrical penetrations used in Darlington are pre-built by Imaging and Sensing Technology Corporation (IST), a Westinghouse company. A drawing of a penetration is shown in Figure 5. The penetration structure is a carbon steel cylinder with end plates containing seven holes for modules (only three shown in cross-section). On the outside of the vault, the penetration nozzle is welded on in-situ. Internally, a structure of tubes supports the cables as they cross the containment wall.

A module consists of a bundle of wires that are crimped onto a single-strand conductor to pass through the containment barrier. There are two crimps on each cable internal to the module - one on each end of the single-strand conductor (see Figure 6).

Darlington has found that some crimps have degraded and a series resistance has built up (even as small a resistance as 0.1 ohms can affect the RTD measurement). The particular mechanism that causes the series resistance is thought to be incomplete crimping [1].

The electrical penetrations for the RTD circuits have a small number of installed spares. In the past, when a problem was detected with the penetration wires, the RTD wires inside the vault could be spliced onto a spare set of cables. During the 1996 outage in unit 2, spare cables were tested and it was found that many of them had developed resistance and were unusable. In order to put three CPM RTDs back into service on unit 2, more spares were required.

There were existing blank electrical penetrations installed directly over the electrical penetrations for the RTD circuits. See Figure 7 for the layout of the penetration inside the vault. These electrical penetrations had structure, but no modules. It was decided that new modules, built to a new specification that increased the quality requirements on the crimps, would be installed in the spare penetrations. New crimp technology is used, but the most important change is that the quality assurance of the modules is increased.

5. Penetration Installation Issues

There were many issues to be overcome in installing the penetrations. These included:

- 1) maintaining or compromising the containment boundary during installation of the new modules
- 2) getting the required sand out of and back into the penetrations
- 3) did the internal support structure exist in the penetrations?
- 4) how many modules should be installed and where? (there were two spare electrical penetrations to choose from)

These issues will be discussed in the following paragraphs.

Originally, the plan was to use a custom flask to maintain the containment boundary; however, the flask could not be used because cable trays blocked its access to the penetrations. Since the flask could not be used, opening the required hole in containment forced us to declare the Negative Pressure Containment System (NPCS) out-of-service, which was allowed partly because all four units were in Guaranteed Shutdown State (GSS) during the installation. Modules were inserted from outside the vault end and pulled through the penetration from inside the vault. See Figure 8 showing a module being pulled through. There was a lot of pre-planning and prerequisites prior to declaring NPCS out-of-service and backout plans were put in place to handle all possible scenarios. In the future, if a module has to be installed, a special, flexible flask that takes advantage of the cabling that makes up most of the length of the modules would be required. Then the penetration can be opened inside the vault and the module pulled through without compromising containment.

The sand used inside the modules for fill and radiation protection is a special dense, dry sand from Russia that pours easily and fills gaps. Replacement sand is difficult to procure, so any sand removed from the penetration had to be kept for replacement after the modules were installed. Sand was removed from inside the vault and had to be transported to another level for storage because of the great weight of sand.

Eight new modules were ordered. Since all of the problems existing in unit 2 were in EP 2263, it was decided to fill EP 2260, the EP directly above EP 2263, with seven modules. The additional module would be installed in EP 2262, above EP 2265. However, when it was discovered that the internal support structure did not exist in any of the spare penetrations, it was decided not to try to install a support structure but to install only two modules in

EP 2260 (above 2263). The modules would be installed at the bottom of the electrical penetration and sand would be used to support the cables. See Figure 9 showing the inside of EP 2262 with one module installed and cables supported by sand.

Installation also included the following tasks:

- 1) installation of new cables between the outside of the electrical penetration and the CDF,
- 2) installation of supports inside the vault to support the weight of the pigtails, and
- 3) installation of additional cable pans for the extra cables

Thanks to the hard work and cooperation of all the work groups involved, the installation was successfully completed and three sets of wires are in use for CPM deltaT measurement.

6. Conclusions

Systematic troubleshooting methods helped us find and resolve RTD faults and allowed us to target our efforts on the most significant sources of trouble.

RTD calibration shifts are real and traceable to a physical effect on the RTDs. The root cause of the shifts is contamination of the platinum wire or other sensor components during manufacture with chlorine, carbon and oxygen-containing compounds.

Electrical penetrations with poor quality crimps have caused problems on three units. Spare modules built to a new specification were successfully installed during the recent station outage.

7. References:

1. Hashemian, H.M., D.D. Beverly, D.W. Mitchell, and K.M. Petersen, "Aging of Nuclear Plant Resistance Temperature Detectors", NUREG/CR-5560, June 1990.
2. "Investigation of Containment Penetration RTD Lead Feedthrough Electrical Resistance Problems", a report prepared for Tennessee Valley Authority by Altran Materials Engineering, May, 1995.
3. Mayer, P., and D. McAllindon, "Analysis of Resistance Temperature Detectors from Darlington NGS", B-MT-97-92-P, to be published.

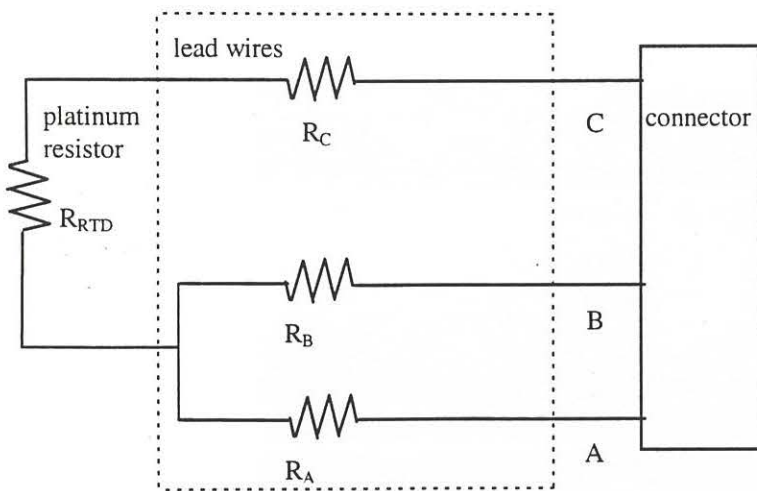


Figure 1. Electrical Schematic of 3-wire RTD

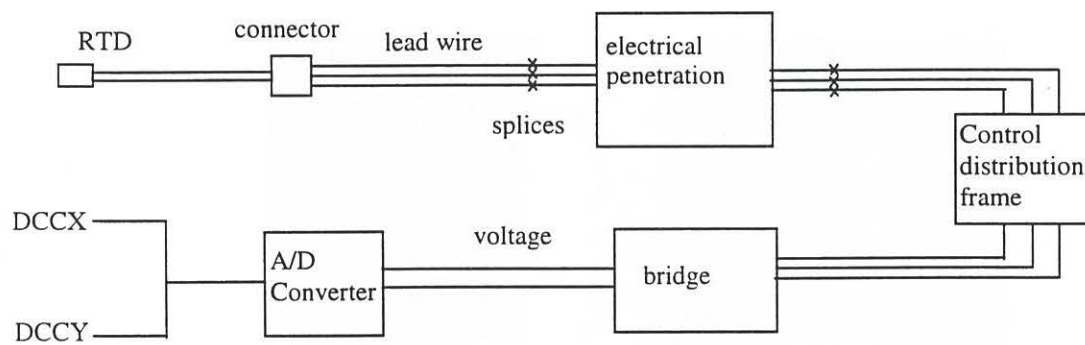


Figure 2. Components in RTD Channel Temperature Monitoring Circuit

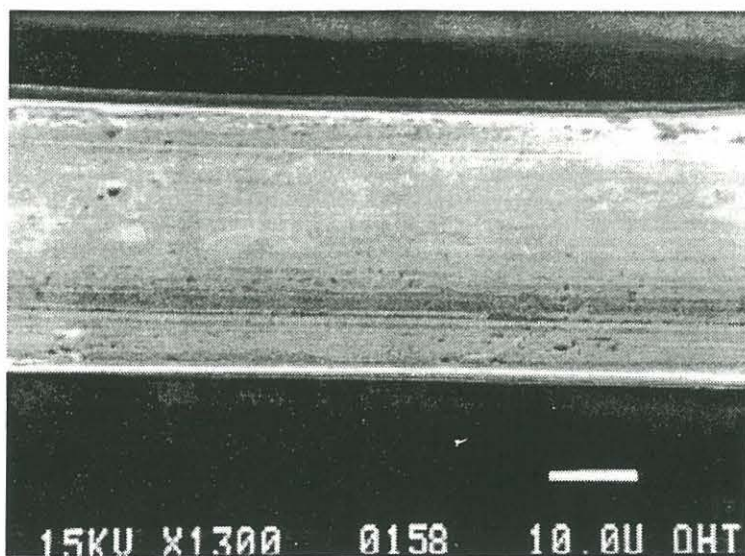


Figure 3. Scanning Electron Microscope Picture of Platinum Wire Surface from Unshifted RTD

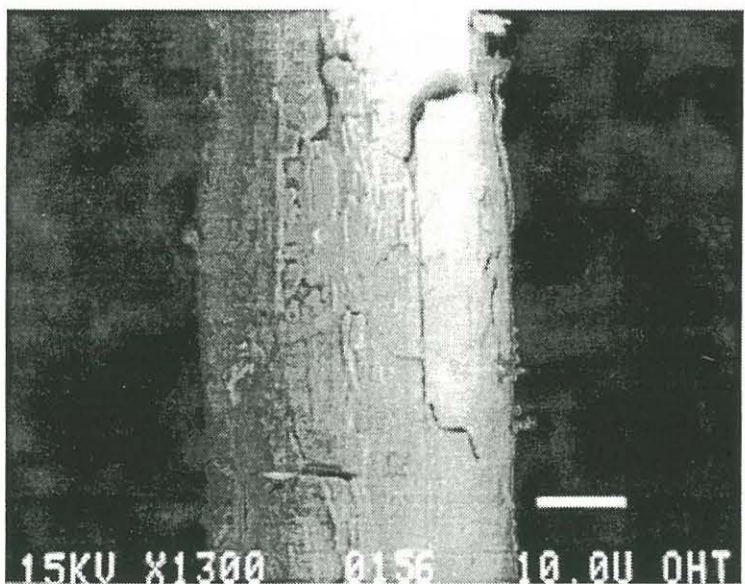


Figure 4. Scanning Electron Microscope Picture of Platinum Wire Surface from Shifted RTD.

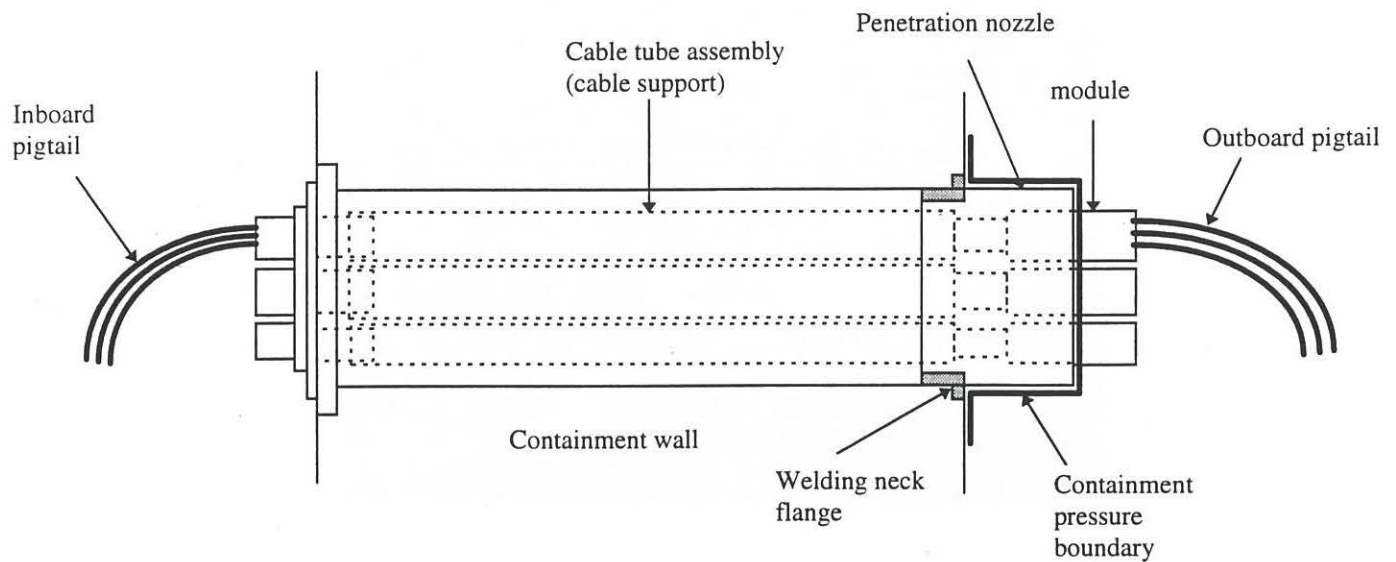


Figure 5. Electrical Penetration Diagram

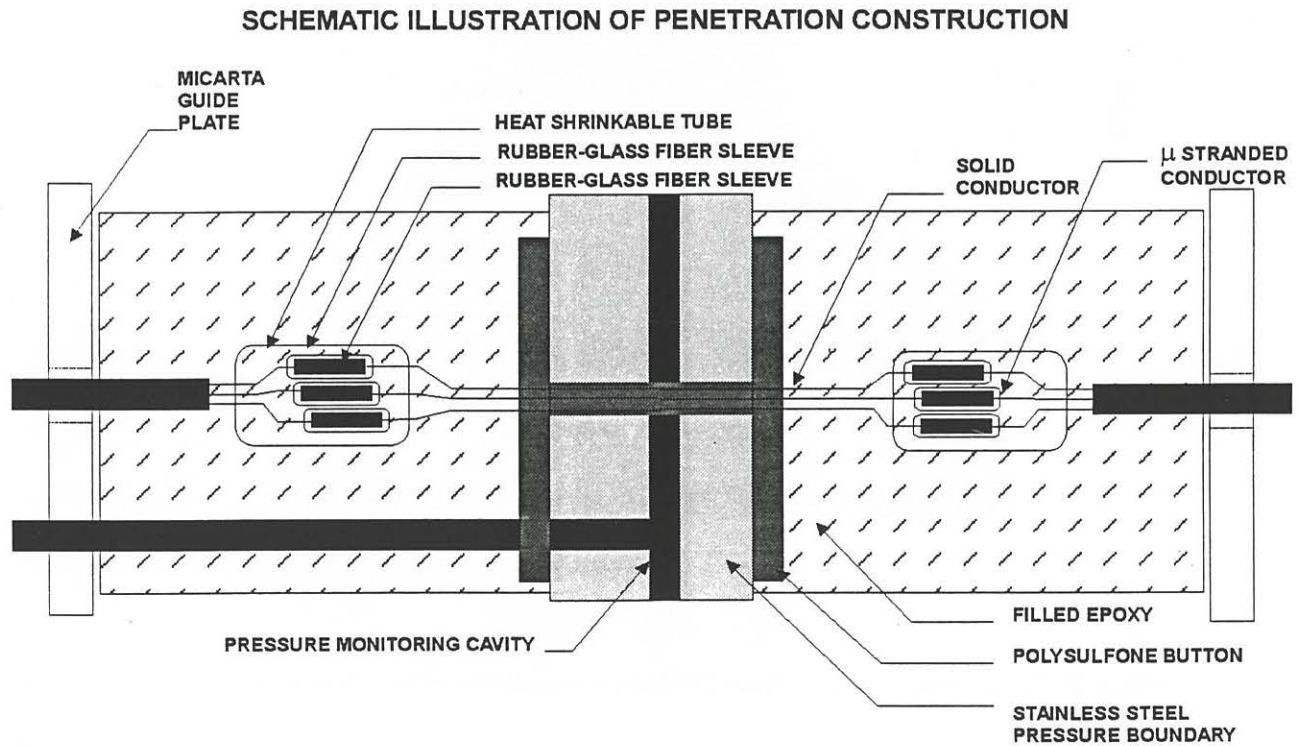


Figure 6. Schematic Illustration of Penetration Construction

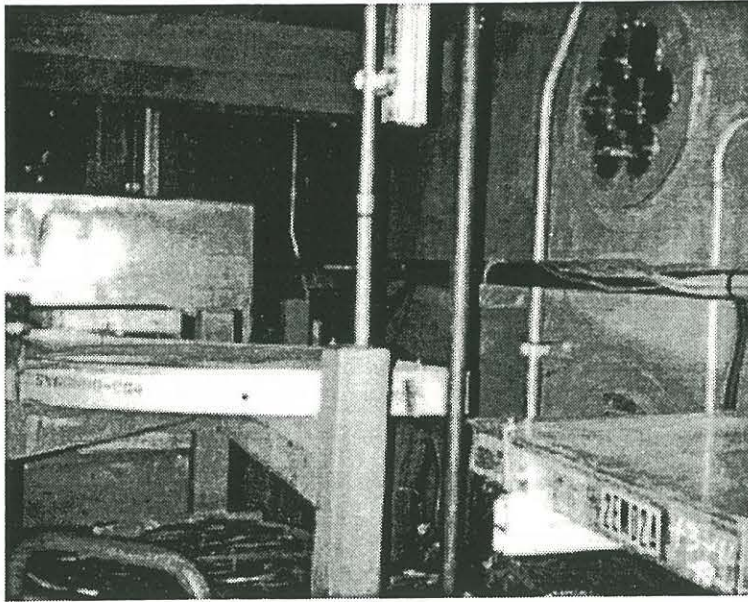


Figure 7. Electrical Penetration Layout Inside the Vault

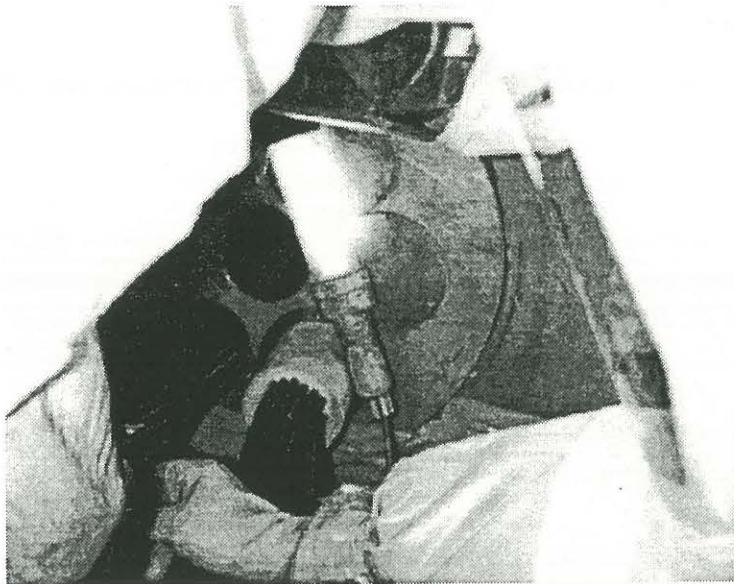


Figure 8. Module Being Pulled Through Electrical Penetration 2260 From Inside the Vault

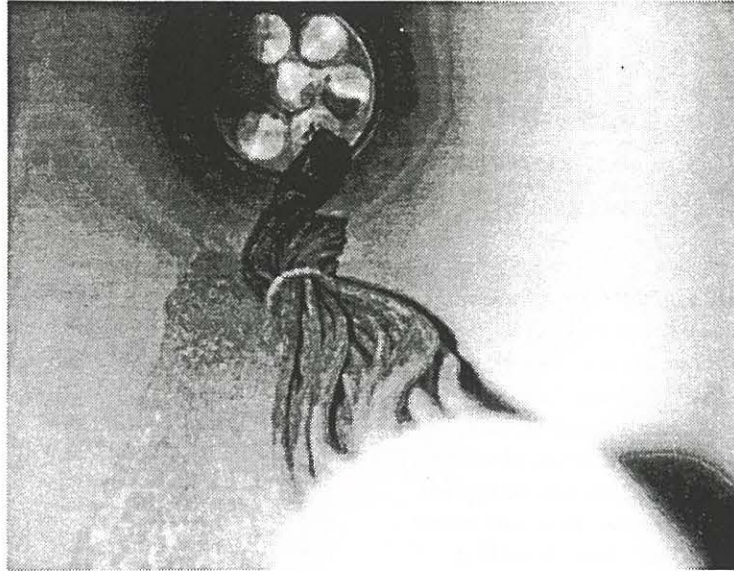


Figure 9. Inside of Electrical Penetration 2262 Showing One Module and Supporting Sand