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ABSTRACT

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PREPP ROTARY KILN SEALS - PROBLEM AND RESOLUTION[1]

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The Process Experimental Pilot Plant (PREPP) is a facility designed to demonstrate processing of low level chemical and transuranic hazardous waste. The plant includes equipment for handling the incoming waste containers, shredding, incineration and cooling the waste, grouting the residue and scrubbing and filtration of the off gas.

The process incinerator is a rotary kiln approximately 8-1/2 ft diameter and 25 ft long with a rotary seal assembly at each end. Each seal assembly consists of a primary, secondary and tertiary seal, with a positive air pressure between primary and secondary seals to prevent out-leakage from the kiln. The kiln operates at 0.5 inch water negative pressure.

From the very outset the kiln seals exhibited excessive drag which taxed the kiln drive capacity and excessive in-leakage which limited kiln temperature. An engineering evaluation concluded that the original seals supplied by the kiln vendor could not accommodate expansion and centerline shift of the kiln resulting from heatup of the kiln and its support system.

Temporary modification to the seals reduced drag and leakage to acceptable levels, allowing satisfactory operation of the kiln for approximately one year to complete the plant testing program, and to develop a replacement seal design.

A totally new concept kiln seal design has been generated to replace the (modified) original seals. This new seal system has been designed to provide a very tight long lasting seal which will accommodate the 1.5 inch axial shift and up to 1 inch radial movement of the kiln shell. Design lifetime of the seal is 10,000 operating hours between major maintenance services while maintaining an acceptable leak rate hot or cold, rotating or stopped.

The design appears adaptable to any size kiln and is suitable for retrofit to existing kilns. A one-third scale prototype seal assembly is being built to verify the concept prior to construction of the 10 ft diameter seals for the PREPP rotary kiln.

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PREPP ROTARY KILN SEALS - PROBLEM AND RESOLUTION[1]

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INTRODUCTION

The Process Experimental Pilot Plant (PREPP) is a full scale pilot plant facility that has been built at the Idaho National Engineering Laboratory (INEL) for thermal processing of mixed hazardous and low level transuranic (TRU) wastes. The facility incorporates a shredder, rotary kiln incinerator, cooling, grouting and off-gas treatment equipment and specialized materials handling equipment.

During the initial start up operations difficulties were experienced with the rotary kiln. The large rotary triple seals at both ends of the kiln failed to provide the necessary sealing function. In particular there was excess air leakage into the kiln and excess drag from the seals, which overloaded the kiln drive system.

This paper describes the original seal design and its problems, a temporary modification to the original seals to permit plant test operations, and the design of a replacement seal system for the kiln.

KILN INSTALLATION

When the PREPP facility was designed in the early 80s, and a rotary kiln was selected for the process, it was realized that exceptionally good end seals would be required for the kiln. Conventional kilns that operate at a slight negative pressure have relatively simple seals to control outside air leakage into the kiln, but do not have a positive seal to prevent leakage from the kiln. Because the PREPP kiln was to process mixed and TRU waste, and it was essential that the spread of contamination from the kiln was to be prevented, a special positive seal system was necessary. Requirements generated at that time specified that the seal assemblies located at both ends of the kiln must have three independent seals in series. Figure 1 is a schematic of the seal assembly. The inner chamber between the first (primary) and second (secondary) seals is pressurized significantly above kiln pressure, such that any leakage past the primary seal would be into the kiln, and leakage past the secondary seal would be into the outer chamber but still inside the third (tertiary) seal.

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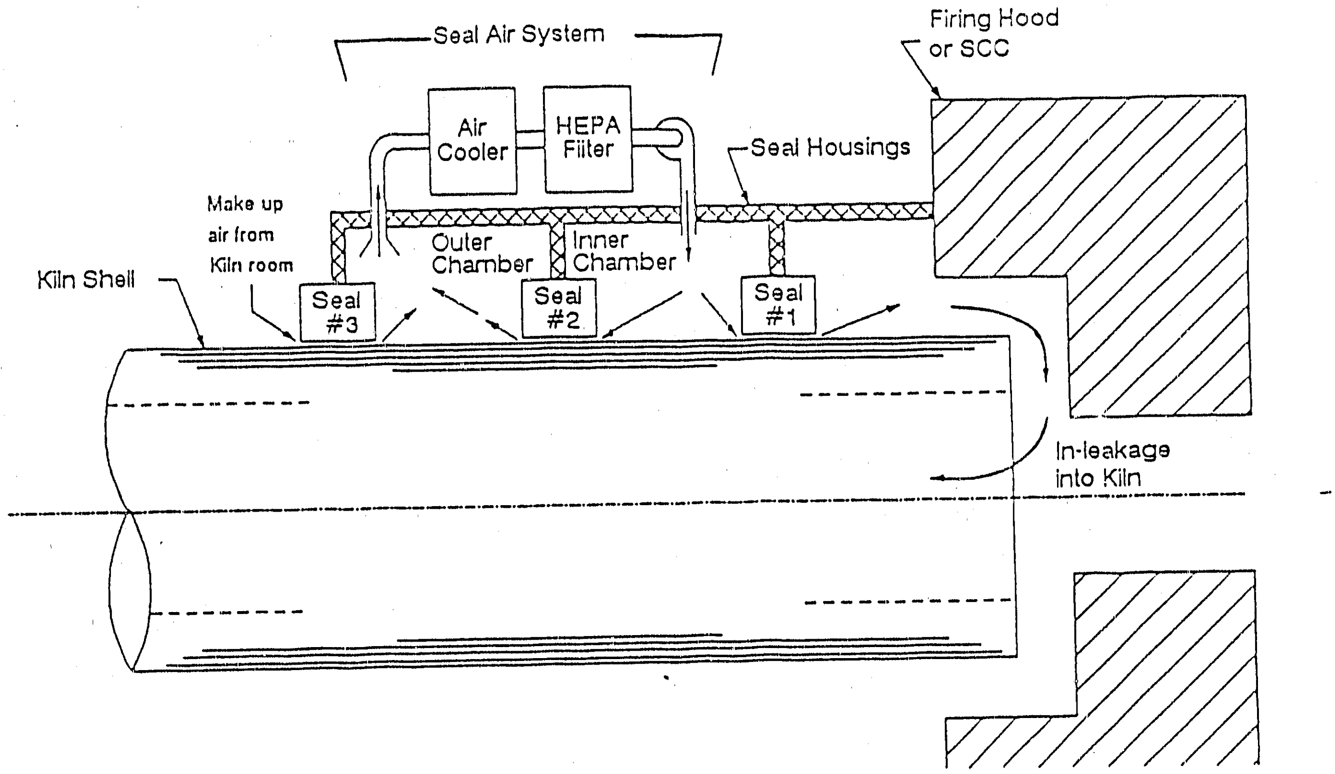

Figure 1 - Schematic of Kiln Triple Seal

A seal air system scavenges air from the outer chamber, passes it through a cooler and a HEPA filter and then returns it to the inner chamber with a Roots type positive displacement blower. A bypass loop is used to establish and maintain the specified pressure in the inner chamber. Intentional leakage in through the tertiary seal balances the system providing make up air for that lost into the kiln.

This triple seal arrangement prevents back flow from the kiln during normal negative pressure operation, during potential abnormal positive pressure transients and during shutdown conditions. Even without the seal air system in operation the three seals are in series between the kiln interior and the kiln room environment.

Normal kiln operating pressure is approximately 1 mm Hg (0.5 in. water) negative with respect to the kiln room. The hypothetical positive pressure transient for the seal design is 517 mm Hg (10 psi) positive.

Vendor selection criteria for the rotary kiln included a heavily weighted factor for vendor design and experience with positive dust tight seals. At that time only one kiln vendor was found who had built a positive kiln seal and could adapt his design to the triple seal concept. The kiln and seals were fabricated by the commercial kiln vendor and were installed by his personnel in the PREPP facility. The kiln and seals were tested for cold rotation but could not be fired for hot testing until completion of the off-gas handling system that was approximately a year later.

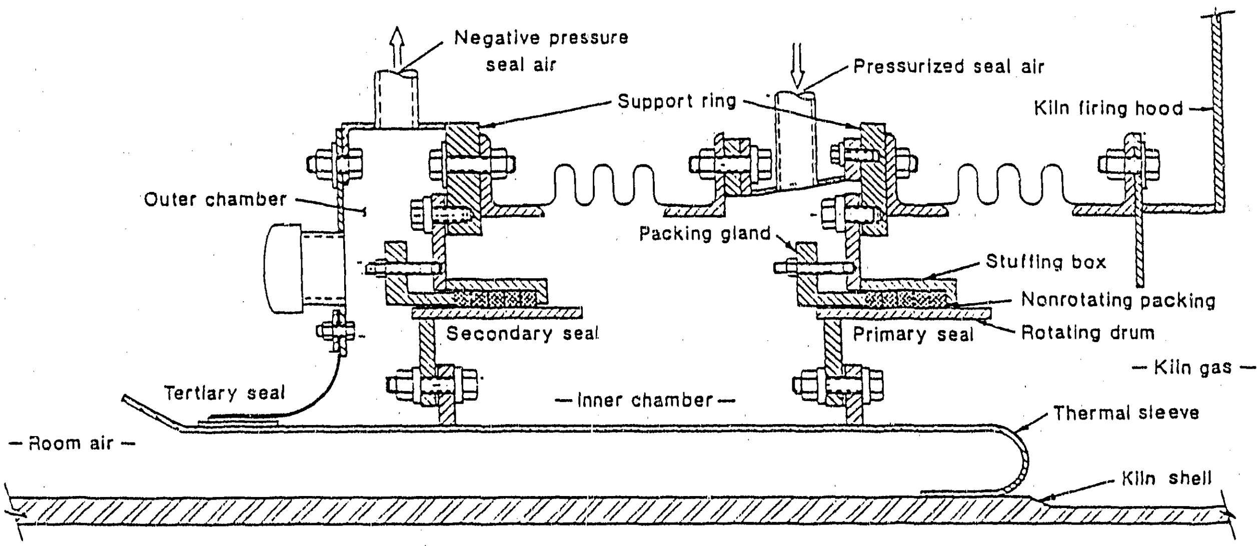

Figure 2 - Original Kiln Seals - Longitudinal

ORIGINAL SEALS

Figure 2 illustrates the original seal design supplied by the kiln vendor. The outermost tertiary seal was a commercial kiln seal (WEBBCO) made up of overlapping spring steel leaves with cast iron rubbing blocks.

The primary and secondary seals were identical in design - rotating drums attached to the kiln shell through a cylindrical thermal sleeve and non-rotating stuffing boxes packed with high temperature packing rings. Carbon fiber packing was used in the primary seal and graphite impregnated fiber in the secondary seal.

Each seal used five rings of packing 1.9 cm (0.75 in.) square in section and 10 m (33 ft) long. The adjustable packing gland compressed the packing axially, forcing it inward to rub and seal on the outside of the rotating drum. Metal bellows were used to seal between the end structures (firing hood and secondary combustion chamber) and the support rings for both seals. The support rings were carried by independently mounted trunnion bearings on solid foundations. Cooling air was ducted into the annulus between the kiln shell and the thermal sleeve to reduce seal temperatures below the 232°C (450°F) operating temperature of the kiln shell.

SEAL PROBLEMS

As the kiln was initially fired and brought up to temperature, irregularities were noted in the combustion process in the kiln, and the anticipated 980°C (1800°F) operating temperature could not be reached. The problem was traced to excess air leakage into the kiln through the large rotary end seals. Also the kiln drive motor current was observed to increase substantially as the kiln temperature increased, and abnormal noises were detected coming from the seals.

The kiln was cooled down and one secondary seal was disassembled for inspection. The packing rings were found to be destroyed and severe scoring was found on the rubbing surface of the rotating drum, on the lip of the stuffing box, and on the packing gland.

EVALUATION OF PROBLEM

A detailed engineering analysis of the damaged seal and its design disclosed a number of deficiencies, two of which caused the observed problems and a third that had the potential to destroy the seal.

These problems were:

1. Splice joints in the stuffing box and packing gland halves were of insufficient stiffness to maintain the shape of those members. Loads resulting from compressing the packing distorted those members causing them to drag against the rotating drum.

2. The drum style seal could accommodate the 41 mm (1.6 in.) axial motion of the kiln due to "float" of the kiln on its rollers and thermal expansion of the shell. However it could not accommodate a vertical shift of the center of rotation of the kiln and rotating drum. The kiln is supported by rollers that bear on a steel tire around the kiln shell. These rollers contact the kiln tire at an elevation approximately 1.25 m (4 ft) below the kiln centerline. As the kiln heats up to operating temperature thermal growth causes the centerline of the kiln to rise approximately 2.5 mm (0.10 in.) above its cold position. The nonrotating seal components including stuffing box and packing gland were, however, rigidly mounted to the support ring that was solidly anchored at its centerline elevation.

   During heat up the rotating drum rising inside the fixed height stuffing box resulted in severe crushing at the top of the seal, opening of a wide gap at the bottom, loss of all packing, and extensive damage to scuffing metal parts.

3. A potential problem was the thermal sleeve attachment to the kiln shell. This joint between the hot kiln shell and the much cooler thermal sleeve was subjected to a myriad of loadings. Differential expansion between kiln shell and thermal sleeve, high drag torque loads from all three seals, cyclic loadings from drum assemblies weight and interferences, and thermal cycles from the cooling air jet contributed to stress at the joint. Eventual fatigue failure of the thermal sleeve to kiln shell joint was very probable.

TEMPORARY MODIFICATIONS

Operation of the kiln for approximately one year was necessary to support plant test operations. A temporary modification was made to the original kiln seals on both ends of the kiln to allow processing non-nuclear test waste. For this test period control of leakage into the kiln was necessary but a positive seal against out leakage was not required.

Modifications included the following:

1. The tertiary seals were removed.

2. Damaged drum surfaces were smoothed.

3. Three of the five packing rings in all four primary and secondary seals were replaced with brass bearing pads.

4. Stuffing boxes and packing glands were allowed to "float" on the support rings by replacing gaskets with brass shims, enlarging bolt holes, reducing bolt shanks and lock wiring bolts in a snug but not tight condition.

5. A system of rods, pivoting lever beams, and counterweights was installed to carry the weight of the stuffing boxes, yet allow them to lift and settle with the rotating drums.

6. Torque rods were added to counter drag torque on the stuffing boxes without restricting vertical or axial motion.

7. The seal air system was not used.

These modifications were successful in adequately sealing the kiln such that operating temperatures were achieved and the kiln drive motor amperage was reduced by 20%. The modifications allowed the full year of test operation but could not meet long term PREPP requirements for reliability and leakage from the kiln.

REPLACEMENT SEAL DESIGN

A replacement seal system has been designed to reduce air leakage into the kiln to a negligible amount and to maintain a positive dust tight seal to prevent contamination leakage from the kiln under all anticipated conditions. This replacement seal system meets all the original seal specifications as well as a set of far more stringent requirements that were developed on the basis of the initial year of kiln operation with the modified original seals.

Figure 3 shows a longitudinal section through the replacement seal design. The moving seal is made by nonrotating rings of graphite carbon rubbing bars bearing against the sides of a smooth faced rotating disc. The disc is attached to the kiln shell by high temperature silicone RTV bedding compound in a steel stand-off structure that is welded to the kiln shell. The thermal stand-off structure and RTV bedding provide structural support, thermal insulation, differential expansion accommodation and seal continuity between the shell and the disc. The kiln shell temperature was measured at up to 232°C (450°F) during operation and the disc temperature is calculated to be 116°C (240°F).

Both sides of the disc are finished in a band approximately 5 cm (2.0 in.) wider than the track of the seal rubbing bars. Other components also have radial clearance to accommodate radial displacement of the disc by 2.5 cm (1.0 in.) in any direction without loss of seal continuity. Centerline shift of the kiln during heatup and cooldown, minor eccentricity of rotating parts or even failure of a kiln bearing will result in displacements less than 2.5 cm.

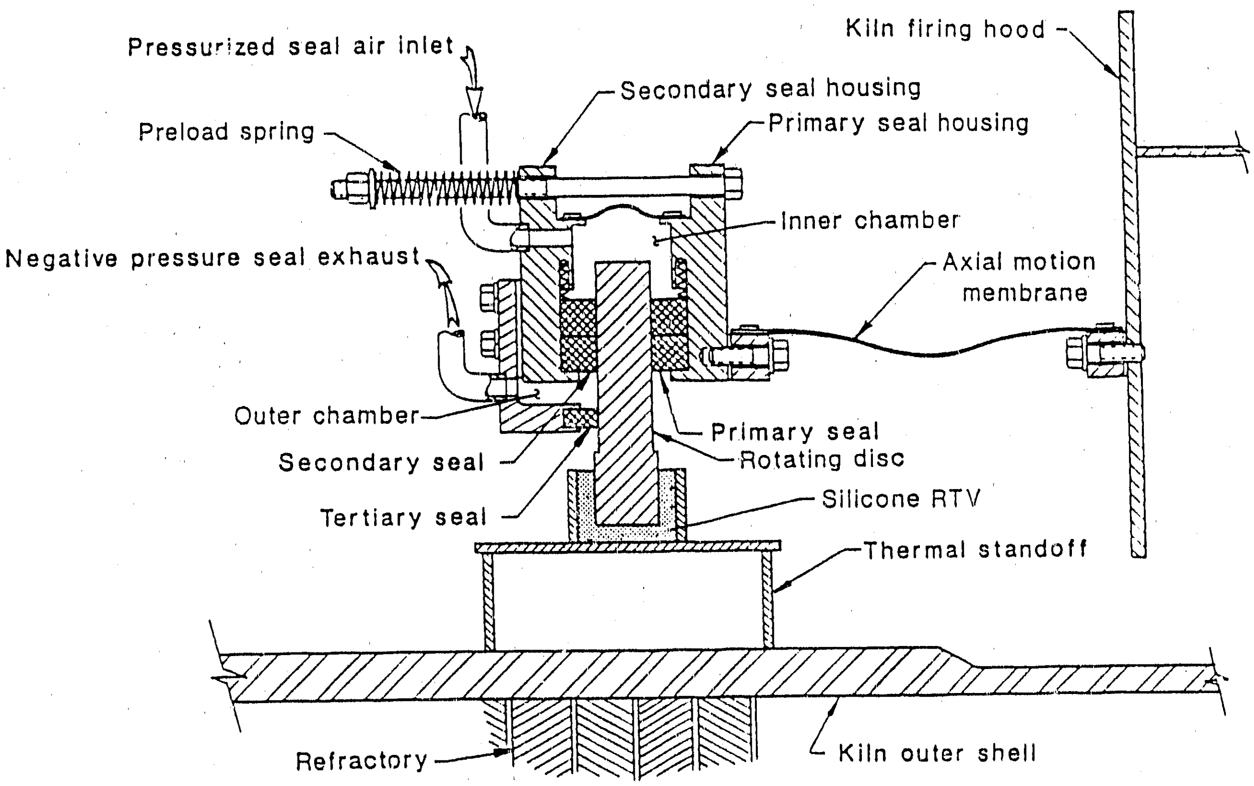

Figure 3 - PREPP Kiln Seal - Longitudinal

The rubbing blocks are solid bars of a high graphite carbon alloy selected primarily for its wear, friction and strength characteristics. Each bar has a 2.54 cm (1.0 in.) square cross section and is 28 cm (11.0 in.) long with a 10 degree tapered section on each end.

Figure 4 illustrates the unique arrangement of 36 seal bars into a full circle with a lap joint between each bar. Contact between blocks at the lap joint is maintained by the preload coil spring and by pressure on the bars from the seal air in the inner chamber. Differential expansion between the steel housing and the carbon bars results in a slip motion of approximately 0.3 mm (0.012 in.) at each lap joint during heatup and cooldown of the system.

The seal bars are held in place against rotation drag by a pivoting stop pin projecting from the housing. A reverse stop pin is also provided to

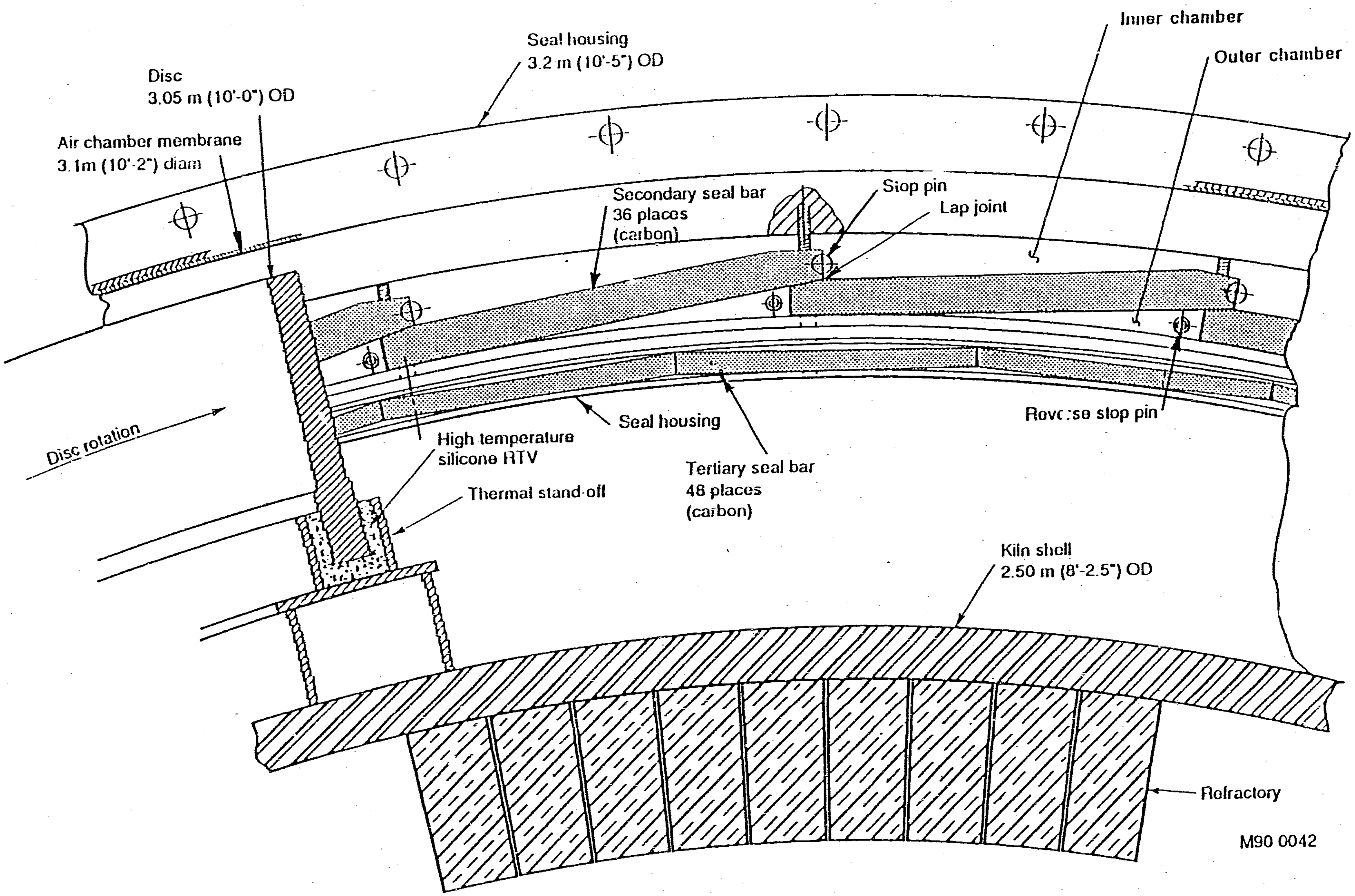

Figure 4 - Kiln Seal Cross Section

prevent disengaging the lap joints in the unlikely event of loss of adhesion between the carbon bars and the RTV bedding material combined with reverse rotation of the kiln.

While the front sides of the seal bars rub against the rotating disc the back sides are sealed to the housing by a 1.8 mm (0.07 in.) thick layer of high temperature silicone RTV. Face pressure of the seal bars against the rotating disc is provided by 72 preload springs over the studs that tie the two seal housings together. The nominal 0.03 MPa (5 psi) face pressure between seal bars and the rotating disc will be adjusted by spring preload and by varying seal air pressure within the inner chamber. As seal air pressure is increased the seal bar face loading is decreased. A balance between leakage into the kiln and seal bar wear will be developed during test operations. Wear rate calculations indicate that the 16 mm (0.62 in.) wear allowance of the graphite carbon seal bars could provide up to 10 years of seal bar lifetime under PREPP operating conditions. Maintenance is expected to consist of an occasional injection of atomized silicone lubricant into the seal air system and adjustment of the preload springs every two years.

Flexible membranes seal between the two halves of the seal housings and between the primary seal housing and the firing hood. These membranes are fiberglass fabric impregnated with a high temperature proprietary material, commonly used for high temperature flue gas seals and expansion joints. The membrane between seal housings allows the gap between housings to close as the seal bars wear. The membrane between the primary housing and the end structures accommodates kiln axial float, thermal expansion of the kiln shell between inlet and outlet seals, and wobble of the disc. Total axial motion capability is 3.8 cm (1.5 in.) at each seal assembly.

The weight of the seal housing assemblies is carried by a pair of vertical hanger rods from an overhead support structure. These hangers allow the housings to swing axially with the kiln shell and rotating disc but hold the housings elevation constant at the center of rotation of the disc. Another pair of tie rods run horizontally in opposite directions from the top and bottom of the housings to resist the drag torque on the housings. These rods will also allow axial motion but prevent rotation of the housings.

The tertiary seal bars are similar to the primary and secondary bars, bedded in high temperature silicone RTV in a shallow groove in the secondary seal housing. However these smaller bars are butt jointed and will separate slightly at operating temperature to allow in-leakage to the outer seal chamber. This in-leakage is necessary to balance the seal air system losses past the primary seal into the kiln. Differential thermal expansion between the carbon bars and the steel housing opens a gap approximately 0.2 mm (0.009 in.) wide at each of the 48 joints around the seal.

MOCKUP TEST

The first test of the disc type replacement seal system will be on a mockup seal using a disc 0.84 m (33 in.) in diameter. The smaller seal will have 18 shorter carbon seal bars where the kiln seal has 36 bars per ring. This mockup seal is under construction at this time and is scheduled for testing on the PREPP rotary discharge conveyor mockup this spring.

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