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ATOMIC ENERGY OF CANADA LIMITED

L'ÉNERGIE ATOMIQUE DU CANADA LIMITÉE

THE CANDU IRRADIATED FUEL SAFEGUARDS SEALING SYSTEM AT THE THRESHOLD OF IMPLEMENTATION

Mise en oeuvre du système des scellés de garantie du combustible CANDU irradié

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Report presented at the INMM 26th Annual Meeting Albuquerque, New Mexico, USA, July 21-24, 1985

Chalk River Nuclear Laboratories

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Résumé

Le développement d'un système de confinement et de surveillance du type "garantie", pour le combustible irradié provenant des centrales nucléaires CANDU, a suscité la mise au point de trois technologies différentes de scellement. Chaque type de scellés utilise un concept différent d'identité. Les scellés ARC (AECL Random Coil) combinent les éléments d'identité et d'intégrité dans la signature en ultrasons d'un enroulement de fils. Deux variantes de scellés optiques se caractérisent par des éléments d'identité en zirconium et à aluminium cristallins. Les scellés à capuchon emploient un sceau à fils modèle X de l'AIEA. Les principales caractéristiques et la valeur relative de chaque type de scellés sont décrites dans le rapport.

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ABSTRACT

The development of a safeguards containment and surveillance system for the irradiated fuel discharged from CANDU nuclear generating stations has inspired the development of three different sealing technologies. Each seal type utilizes a random seal identity of different design. The AECL Random Coil (ARC) Seal combines the identity and integrity elements in the ultrasonic signature of a wire coil. Two variants of an optical seal have been developed which feature identity elements of crystalline zirconium and aluminum. The sealed cap-seal uses a conventional IAEA "Type X Seal" (wire seal). The essential features and relative merits of each seal design are described.

GENERIC SYSTEM DESCRIPTION

Containment Assembly

CANDU reactors are refuelled on power with natural uranium bundles. A 600 MW(e) station may discharge approximately 5000 irradiated fuel bundles per annum into the storage bay. The bundles are automatically or manually placed in trays with 24 to 26 bundles per tray. The safeguards containment and surveillance system design requires the interlocking trays to be stacked on bases in the bay to a height of 19 or 20 trays (Fig. 1). The design of this system was previously reported (1).

Stack Cover

A cover is fitted over two adjacent stacks of trays and is secured to the common base by two tie rods. This assembly is required at some stations for seismic qualification as well as for safeguards purposes.

A stainless steel collar, called a 'doughnut', is fitted to each tie rod. This serves to lock the upper end of the tie rod to the cover, preventing the rod from being unthreaded and to restrict access to the rod and seal. The cap seal, a cylindrical nut, is threaded on to the top of the tie rod to seal the doughnut to the rod. A dust cover is fitted to the seal to reduce the risk of accidental damage arising from bay operations and to prevent the accumulation of debris or fouling on the seals. The cap seals are approximately 5 cm in diameter and 8 cm high.

Installation Tools

The tie rod is initially fitted with a protective cap to prevent damage to the seal threads. It is lowered with a simple hook on the bay hoist. The rod installation tool engages the square body of the tie rod top to enable the operator to screw the rod into the base receptacle. The base receptacle has an entry cone to facilitate alignment. A pull test is made with the hook tool to ensure that the threads are engaged. These tools are illustrated in Fig. 2. Any sealing scheme similar to these would require an equivalent complement of remote tools.

The steel doughnut is fitted into the lowering tray and is secured with the cap seal threaded onto the hollow stud in the centre of the tray base. The dust cover is fitted to the seal. This assembly is lowered with the bay hoist to the stack cover. The dust cover is removed and temporarily stored with a hook tool. The seal is removed with the seal installation tool and remains captive in the tool head. The doughnut is lifted from the tray with a handling tool. This assembly is maneuvered with the assistance of the bay hoist connected via a compliant coupling. The doughnut is lowered to engage the square body of the rod top. This assembly is rotated (unthreading the rod slightly) until the doughnut engages four keys on the stack cover, locking the rod to the cover. The doughnut handling tool is removed. The long tools are stored suspended from the gantry railing by means of hooks during operations with the system.

The protective cap on the tie rod is removed with a mating tool. The cap seal is then installed on the rod, with the non-return pin engaging the collet in the rod top. The seal cover is fitted to the seal. The rod protective cap is threaded onto the stud in the tray, and the tool removed. The tray assembly is recovered with the bay hoist. Only the tray, the rod protective cap, and the lowering hook are required to be removed from the bay water. These items are monitored for contamination, decontaminated if necessary and stored in plastic bags. The long tools are stored with the working length immersed in the bay on a rack.

To access any of the seals, the bay gantry is positioned over the desired location. The hook tool is used to remove and temporarily store the dust cover. Associated with each seal type are specific installation and verification tools.

AECL RANDOM COIL (ARC) SEAL

The particular features of the ARC seal system are addressed in detail in a companion paper (2). Briefly, the identity and integrity element consists of a 302 stainless steel wire formed into an irregular coil with little manufacturing control over its precise form. The wire is housed in a cavity in the seal nut. It is connected to the upper end of the seal nut and to the non-return pin below the fracture link. Removal of the seal breaks the pin and deforms the coil until it fails. The ARC Seal installation tool is keyed to the seal nut, and engages a circumferential groove near the nut base with a spring loaded ball coupling.

The ARC seal is verified with an ultrasonic reading head (Fig. 3a) which is positioned with a removable placement tool. The tool is keyed to the reading head for azimuth control. Corrosion resistant balls are positively displaced to engage a groove in the mating socket on the head. The reading heads have integral, 110 VAC powered flushing pumps to remove air bubbles from the ultrasonic measurement volume. These reading heads are lowered into the bay on a base assembly with the bay hoist. The umbilical cables are paid out from storage reels as the heads are lowered. The reading head base incorporates a reference target, the 'calibrate seal' which is used to monitor the system performance characteristics.

On removal from the bay, the cables, reading heads and the base unit are wiped, and are stored in plastic bags in the sealed cabinet in the bay area. The power distribution system supplied provides for either 110 or 220 VAC mains operation and incorporates a ground fault interrupter.

The identity of the seal (Fig. 4) consists of the time series signal obtained by the backscattering of ultrasonic energy from the seal coil volume as acquired with a reading head assembly and a Seal Pattern Reader (SPAR) (3). The reading head assemblies with their specific transducers contribute to the character of the seal 'signature' and are considered to be unique and non-interchangeable elements of the system. The head design incorporates an annular target which is used to estimate the sound phase speed in water, and which acts as a timing reference for the seal signature acquisition.

The identity is verified by comparing a seal signature with the established historical reference signature for the specific seal and reading head combination. This is accomplished in the SPAR by digitally computing a correlation coefficient of the present observation with data recorded on a magnetic bubble cassette. A minimum threshold of 0.7 is recommended to qualify a pair of signatures as representing the same seal and reading head pair.

Two reading heads are required to provide continuity in the case of a reading head failure and to minimize the systematic false alarm probability associated with instabilities in the reading head characteristics.

OPTICAL SEAL

Identity and Integrity Element

The optical cap seal system development has been reported recently (4). This seal (Fig. 5) has bayonet slots on the seal nut which are engaged with pins on the seal installation tool. During installation, a protective pad is driven down against the top of the seal to retain the bayonet engagement and to relieve the optical seal identity element from mechanical loads arising from the non-return pin engaging the collet.

The optical cap seal is formed by setting a 3.5 cm diameter prepared disc of 99.99% "Superpure" aluminum in the top of the seal nut (Fig. 5). The identity is the upper visible surface of this disc. The preparation consists of etching in an aqueous solution of hydrochloric acid, nitric acid, and hydrofluoric acid. The crystal patterns arise from the etch pits developed in the as-cast aluminum. These patterns have an appearance which depends markedly on the direction of the illumination. This phenomenon is used to verify that the seal has not been replaced with a photographic copy by observing the changes in the brilliance of crystal features as the illumination sources in the verification tool are alternately powered.

The integrity of the element is formed by milling a deep circular slot in the back of the identity to form a weak annular area concentric with the centre of the disc. The central area is connected to a non-return pin which engages with the collet in the tie rod. Removal of the seal pulls the centre of the identity out of the seal body. The aluminum identity deforms plastically before breaking, irreversibly altering the pattern in a manner which precludes cosmetic re-assembly.

Development work underway includes dielectric isolation of the aluminum element from the stainless steel seal body and pin to reduce the effects of galvanic corrosion.

A previous design considered the application of a pure zirconium identity element. In this instance, patterns with crystals of 0.5 to

1 cm diameter have been grown in crystal bar zirconium by thermal cycling in vacuo between 1000°C and 300°C followed by chemical polishing and oxidation for one hour at 500°C. These elements have both shape and colour. The polarization of the incident illumination may be altered to vary the contrast in the crystal pattern to prove that the seal has not been replaced by a photographic copy. This property of the zirconium seal has not been demonstrated under application conditions.

Identity Inspection and Verification

A variety of optical inspection techniques have been investigated for verifying the seal identity. A commercially available radiation tolerant, submersible television camera mounted in a support structure, (Fig. 3b) is used to inspect the identity and integrity element. This tool engages a bayonet slot of the doughnut and the central cavity for concentric and azimuthal alignment. The tool is maneuvered with a placement pole identical to that described for the ARC reading head above. The illumination from either of two lamps may be selected. One illumination position is defined as the 'Identity' position and the other is the 'Check' position. The 'Identity' is observed on a monitor and recorded with 'instant' photography or other means such as a video recorder. The photographic record of the image may be visually compared with the reference photographs for the seal either directly or by means of negative positive superposition. The changes in contrast observed when switching between the 'Identity' and 'Check' positions serve to verify that the identity element is not a facsimile.

Operation of the TV camera inspection system requires vertical agitation to flush bubbles from the camera lens.

On removal from the bay, the cables and the optical assembly are wiped. These are stored in plastic bags. An AC power distribution system similar to that for the ARC sealing system is used.

X-CAP SEAL

Identity Element

The X-Cap seal is an adaptation of the Type X Seal developed at the Sandia National Laboratories for the IAEA. The Type X Seal development and comparison to the Type E Seal is described in an ISPO Report (5).

The X-Cap seal arrangement as shown in (Fig. 6), consists of a 304 stainless steel nut which includes the non-return pin, an uncoated stainless steel aircraft cable (7X7, 1.19 mm diameter), and the Type X Seal assembly. The latter is composed of a stainless steel cup-like body (25.4 mm diameter by 9.53 mm) with spring washers and a tanged plug. Prior to assembly the identity patterns are scribed on the spring washers and the inside surface of the plug, and recorded for future comparisons at IAEA Headquarters.

For assembly, the wire is fed through the seal nut and the hole in the non-return pin. The wire ends are passed through the bottom of the seal body, drawn tight and secured together with a stainless steel crimp. The tanged plug is snapped into the body where it is retained by the action of the spring washers after the tangs engage the groove. The seal assembly is installed with the same tool as used for the optical seal.

Verification

The X-Cap Seal Removal Tool (Fig. 3c) mates with the bayonet slots on the seal nut. A lever action slides a spring loaded rod underneath the Type X Seal body through a slot on the top of the seal nut. The inspector pulls upward on the tool to determine whether the seal wire is still intact. The tool may then either be disengaged or the inspector may choose to cut the seal wire and recover the Type X Seal assembly.

To sever the wire a weight is raised within the tool and dropped onto a chisel. To deter the potential divertor from cutting the seal wire and effecting a repair, the inspector may change the cut position to the other side by rotating the tool 180 degrees, or may elect to change to a chisel with a different cutting geometry. This latter action requires removing the tool from the bay (or selecting from a number of similar tools). Once the wire is cut the Type X Seal body is retained in the tool head. The assembly is lifted clear of the seal nut, withdrawing the wire end and releasing the non-return pin. The Type X Seal body and wire assembly may be deposited in the (doughnut) lowering tray by retracting the spring loaded rod. The tool illustration in Fig. 3c is a compound view. The weight-chisel action and the spring loaded rod are in orthogonal planes. The seal nut may be removed from the rod and installed on the stud in the tray for recovery and refitting for reapplication.

Preliminary tests on seals submerged in the experimental bays of the NRU Reactor have shown that seals are readily decontaminated for shipping to Seibersdorf, Austria using Type A packages as defined by IAEA transport regulations (6). Further decontamination may be required following opening prior to verifying the seal identity markings. The seal wire may be inspected for length and repairs as part of the verification.

Metallurgy

The basic configuration of the Type X Seal has been maintained. The seal materials have been changed to be more compatible with immersion in the CANDU irradiated fuel bays. The seal body and spring washers remain a 303 stainless steel. The tanged plug has been changed to a 17-4 PH stainless steel. The plastic coating conventionally used on IAEA seal wire degrades in the radiation fields of the bay and has been deleted. The standard aluminum crimps are replaced with stainless steel splicing sleeves.

Seals of this design are undergoing proof testing in the laboratory and an irradiated fuel bay to examine corrosion and to extend the experience with decontamination.

COMPARISONS

Features

The characteristic features of the three candidate seals which may be compared are:

- is the seal identity verifiable in situ?
- is the seal integrity verifiable in situ?
- is the seal vulnerable to corrosion?
- is the seal vulnerable to (accidental) mechanical disturbance?
- what are the implementation and operational costs?

These comparisons may be summarized readily, apart from costs. None of the sealing systems have been procured on a commercial scale with the appropriate levels of quality assurance to permit precise costs to be defined. The costs per seal are similar, on the order of $300 (Canadian) in reasonable quantities due primarily to the machining of the seal nut. This comparison is summarized in Table I.

The X-cap seal tooling permits an in situ pull test on the Type X Seal prior to its (optional) removal for verification. This is consistent with the IAEA procedures for Type E Seals. The corrosion tolerance of the revised Type X Seal is under study at the IAEA and AECL Chalk River Nuclear Laboratories. Preliminary tests indicate that corrosion will not be a problem. The seal bodies may be re-used with new seals and replacement non-return pins.

The ARC seal is acknowledged to have systematic false alarm and missed alarm probabilities. The estimation of these parameters is discussed in a companion paper (2).

The optical seal is considered to have an extremely low false alarm rate in the absence of corrosion with no systematic mechanisms having been identified. The missed alarm rate is difficult to quantify. For the limited number of identities manufactured to date, no pairs have been observed which are not readily distinguishable. The potential for replication of a specific seal identity is believed to be very remote.

The Type X Seal performance characteristics are presumed to be similar to those of the Type E Seals which have widespread application by the IAEA.

Distribution of Complexity

While the issue of costs for the sealing systems may not be readily addressed at this time, it is useful to examine the relative distributions of complexity associated with the systems. Table II illustrates this comparison. Fundamentally the ARC and optical seals place the verification of the identity and integrity of the seal with the inspector on site. To accommodate this decision, both seal systems require sophisticated electronic and mechanical access to the seal through the 5 m of bay water. The routine application of either system will involve repeated deployments of the submersible electrical and electronic assemblies and cables, and operation of the supporting instrumentation in the bay environment. Such systems are vulnerable to common failure modes such as damage to connectors and seals, and abrasion of cable jackets. Successful application of such systems by the IAEA will require scheduled technical maintenance. A performance monitoring program is recommended for the ultrasonic and optical sealing systems.

The ARC and optical seals are considered to be verifiable in situ. The optical seal aluminum identity element is vulnerable to corrosion in the bay environment should the isolation mechanisms fail (this would not be the case for the zirconium element). All seals, with the protective caps and doughnuts in place are not considered to be vulnerable to accidental mechanical disturbance.

The X-cap Seal alternative is free from the 'high technology' concerns discussed above. The complexity of the operations at the reactor irradiated fuel bay is dominated by the requirement to remove contaminated seals, decontaminate the seals for transport, and arrange for secure transportation to the Seibersdorf Laboratory near Vienna. The seals policy of the IAEA will determine the numbers of seals to be processed and the scale of the required action at the reactors and Agency Headquarters. The level of the decisions assigned to the inspector on site is similar to that of the existing Type E Seal procedures, namely verifying the seal attributes and the integrity of the wire prior to removal.

CONCLUSIONS

The requirement for a safeguards containment and surveillance system for the spent fuel discharged from CANDU nuclear generating stations has inspired the development of three different sealing technologies. Seals, remote tooling and associated hardware have been developed for these three technologies such that all are at the threshold of implementation.

The aluminum optical identity is considered to be an attractive candidate for other seal applications such as conventional Type E and Type X Seals, 'tie' seals, or self-adhesive seals. Given the high visibility and random nature of the crystal pattern, this type of iden-

TABLE I

SEAL SYSTEM DESIGN COMPARISON

FEATURE	ARC SEAL	OPTICAL SEAL	X CAP SEAL
Identity Element	SS wire coil in a cavity	metal disc of Al or Zr	IAEA Type X Seal (internal marks)
Integrity same as Identity?	yes	yes	no, seal body and wire
In situ verifiable	yes	yes	no
Verification	ultrasonic signature correlation with reference signature	optical inspection via remote TV, comparison with reference photograph	remove, decontaminate return to IAEA Headquarters for visual comparison to reference photograph

TABLE II

SEAL SYSTEM COMPLEXITY COMPARISON

FEATURE	ARC SEAL	OPTICAL SEAL	X-CAP SEAL
Complexity - on site			
installation tools	**essentially common to all types**		
inspection tools	precision	precision	simple
high technology electronics	custom	commercially available	none
submersible power (GFI protected)	yes (pump)	yes (TV, lights)	none
processing	automated	simple image comparison	decontamination, packaging, shipping
Complexity - Agency Headquarters			
data base	computer files of signatures	**photographic album of images**	
processing	analysis re stability, errors	none	dissassembly, decontamination, verification
Stability	transducer limited, requires two reading heads	**corrosion and fouling limited**	
Minimum Recommended Reading Interval	one year	**not determined (greater than one year)**	

tity element may offer improved performance over present methods.

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5. D.L. Poli, "ISPO Task E.28, Metallic Seals", Program for Technical Assistance to IAEA Safeguards, U.S. Department of Energy, ISPO Report No. 133, February 1981.

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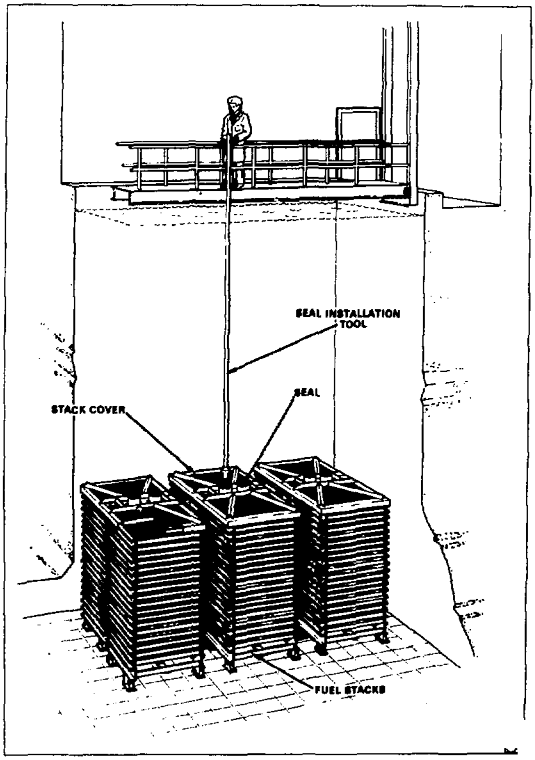


Figure 1a
Safeguards Containment Units in Irradiated Fuel
600 MW CANDU

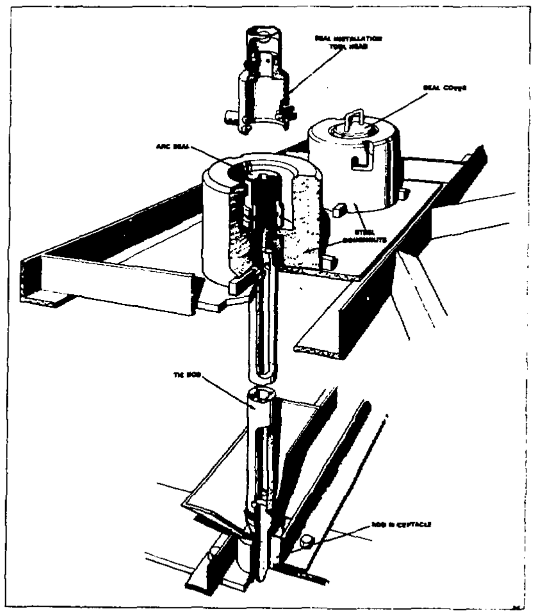
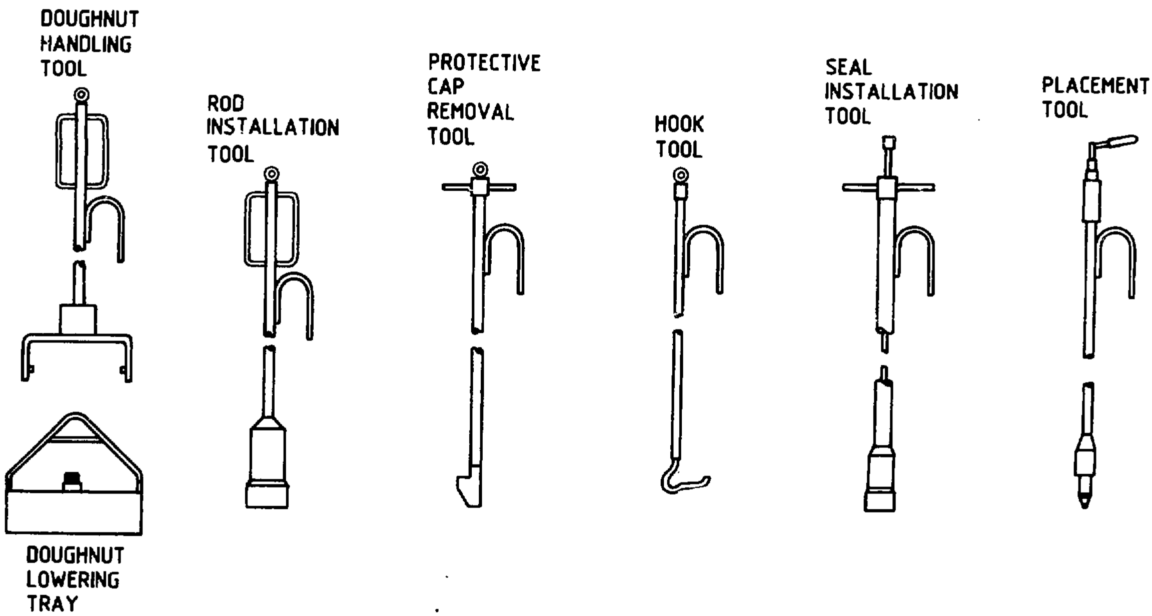


Figure 1b
Containment Unit Cover Sealing Detail



SEALING TOOLS

Figure 2

(a) Ultrasonic Seal Reading Head

(b) Optical Seal Inspection

(c) X-Cap Seal Removable Tool

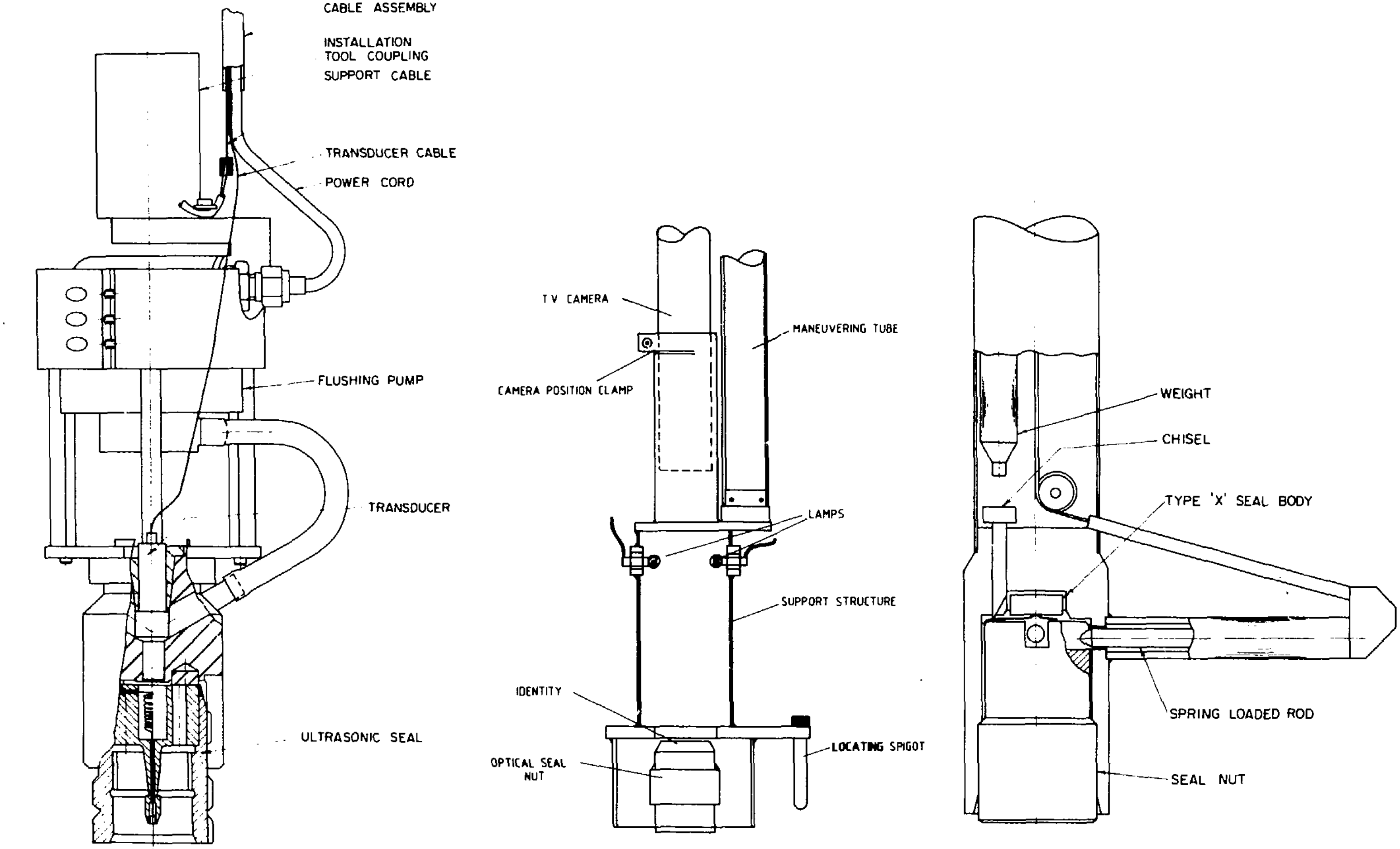


Figure 3

Seal Identity Verification Tools

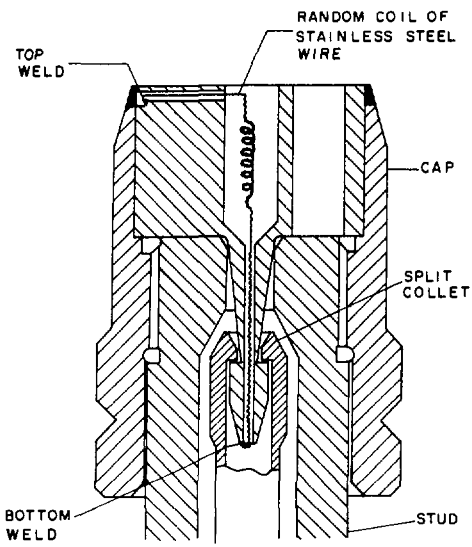


Figure 4a
Ultrasonic Seal Cross Section

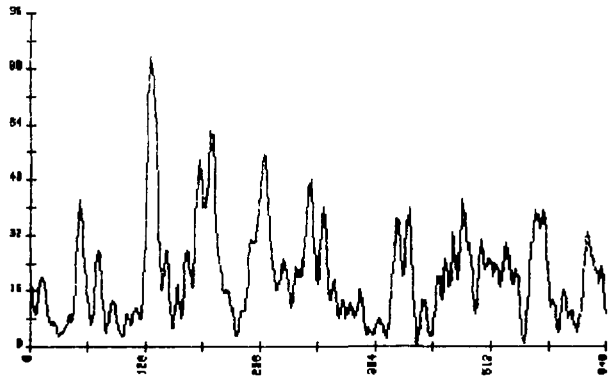


Figure 4b
Ultrasonic Seal Signature Time Series

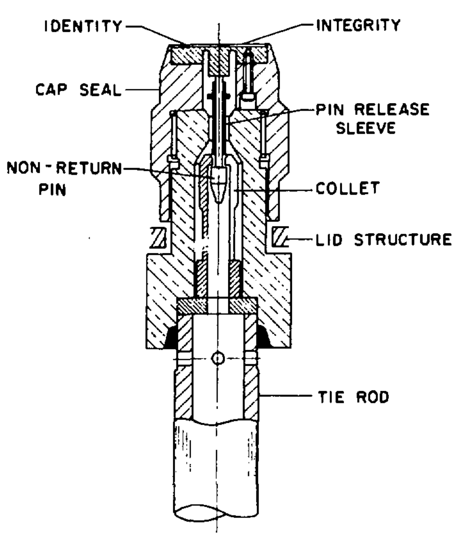


Figure 5a
Optical Seal Cross Section

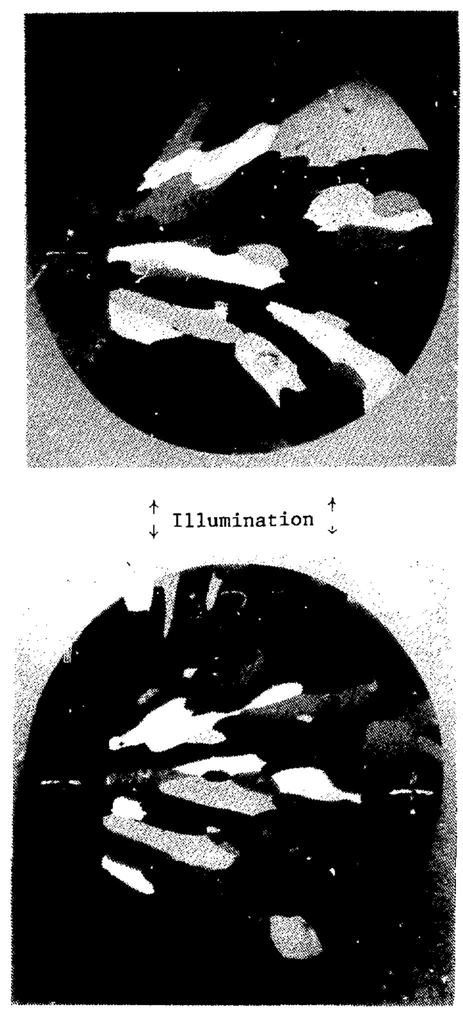


Figure 5b
Aluminum Identity

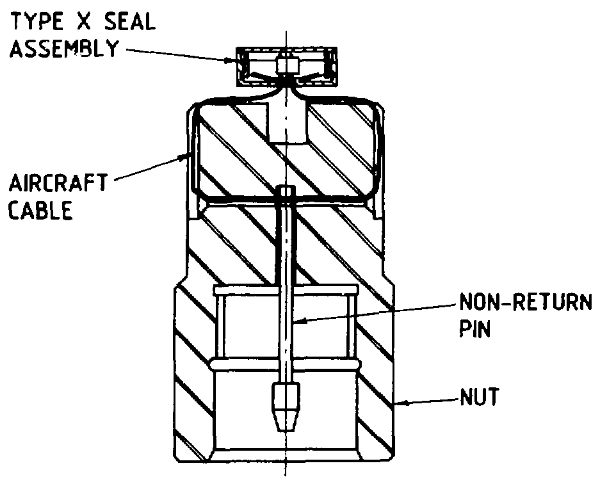


Figure 6a
X Cap Seal Cross Section

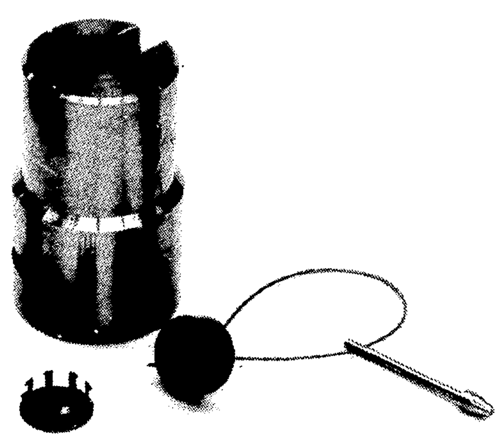


Figure 6b
X Cap Seal Nut, Type X Seal Partially Assembled,

Non-Return Pin

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