DEVELOPMENT OF SEALS FOR SAFEGUARDS

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ABSTRACT

During the last several years, effort has increased to improve existing seals and to develop new seals for international safeguards. Sandia National Laboratories is participating and this paper reports on the status of the Sandia programs.

INTRODUCTION

Sandia National Laboratories, sponsored by the Department of Energy (DOE) and the Program of Technical Assistance (POTAS) to the International Atomic Energy Agency (IAEA), is improving existing seals and is developing seals and sealing systems for possible use by the IAEA. Several metallic seals, currently in wide use, were improved and their verification techniques reviewed. The IAEA is presently testing a Sandia electronics seal. An in situ verifiable fiber optic seal system was developed to improve the timeliness of seal verification. The development of a Fuel Assembly Identification Device (FAID) to seal BWR fuel assemblies is approaching the in-reactor test stage.

METALLIC SEALS

Our object is to design a sealing system which is superior to that currently used but equally easy to apply and verify. The metallic seal currently used by the IAEA is a cup or Type E seal. This seal consists of three sheet metal stampings, two of which are fastened together to form the bottom of the seal. The third stamping forms a solid top piece. The seal is installed by threading wire through the item to be sealed and then through the holes in the seal bottom. The wires are then tied together or joined with a crimp-type seal or other device. The top is snapped into the bottom which allows the fingers in the bottom to engage the top, thereby capturing the wire juncture within the metal cup enclosure.

Two of the improved seals were modifications to this design while the third was a completely new metallic seal. The three systems developed are: 1) The Resin Coated Type E Seal, 2) The Double Cap Seal, and 3) The Type X Seal.

The resin-coated seal shown in Figure 1 uses a resin, tamper-indicating layer in the bottom of the seal. The resin is applied by melting the resin granules in the bottom. As the bottom cools the resin cracks creating a unique finger-print of cracks and bubbles. The top is scribed to provide an additional unique identification.

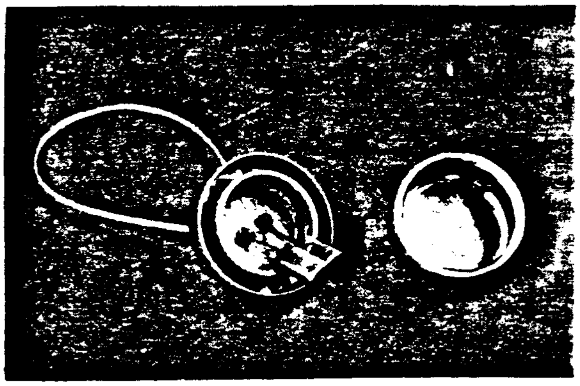


Figure 1: Resin Coated Type E Seal

The Double Cap Seal shown in Figure 2 is made from a Type E Seal but with a 2.54 cm diameter cup seal top. A 1.25 cm hole is made in the Type E seal top and the top is then soldered to the larger top. Solder and scribe lines form the unique fingerprint in both the top and bottom of this seal.

The Type X seal shown in Figure 3, unlike the Type E seal, is not a standard commercial product. It is a stainless steel design which can be made by most machine shops. The plug has spring fingers which are locked into a groove when inserted into the body. Scribe lines provide the unique identity for verification.

Fiber Optic Seal System

Direct visual, electronic, and photographic verification were considered for the fiber optic seal. No practical method for direct visual verification was found. The technology for a practical photographic verifier was available while the electronic technology required development. Thus, we commenced development of a prototype system with photographic verification. Also, a feasibility study was initiated to determine the practicability of verifying the fiber optic seal electronically.

General specifications for the fiber optic seal and photographic verifier were established in cooperation with the IAEA. Requests for quotations to produce one prototype verifier and 20 fiber optic seals in a six month period were sent to selected suppliers. Atlantic Research, Arlington, Va. was the successful bidder and began work in July, 1980.

The prototype system was completed in December, 1980. The IAEA and the Euratom Safeguards Directorate were favorably impressed during demonstrations at Vienna and Luxembourg in February, 1981. The IAEA has endorsed the continuation of the program. Approval to procure field evaluation systems was obtained from DOE/ OSS. Three verifiers and 200 seals are to be fabricated and delivered to the IAEA by the end of January, 1982.

The system was designed to be a field deployable unit providing a secure seal that is capable of quick and accurate in situ verification of the integrity of the seal.

The system consists of a seal body, a length of fiber optic cable, a seal installation tool, and a seal pattern recorder/ verifier. The photographic recorder/verifier, 20 seal bodies, 15 meters of fiber optic cable, three packs of Polaroid SX-70 film, and the seal installation tool are carried in a shoulder satchel. A transit case provides space for the satchel, an additional 80 seal bodies, 100 meters of fiber optic cable and seven packs of film.

The seal (Figure 5) has a loop which consists of a 2.2 mm diameter polyethylene sheath containing a multiconductor (sixty-four 0.127 mm diameter fibers) plastic fiber optic light guide terminating in a two-piece molded plastic seal body. Metal serrated blades within the seal body act to sever the sheath and about 50% of the fibers when the seal is closed. The terminated ends of the loop are trimmed flush with the seal body to provide a window for viewing the fiber ends. When the window is illuminated, only the uncut fibers become fully illuminated. This results in a pattern (Figure 6) which is unique to each seal.

The seal pattern is photographically recorded. Light to identify the seal pattern is first polarized. It then passes through a beam splitter which is coupled to the seal window by a flexible coherent image guide. The light output from the illuminated fibers is returned to the camera through the same

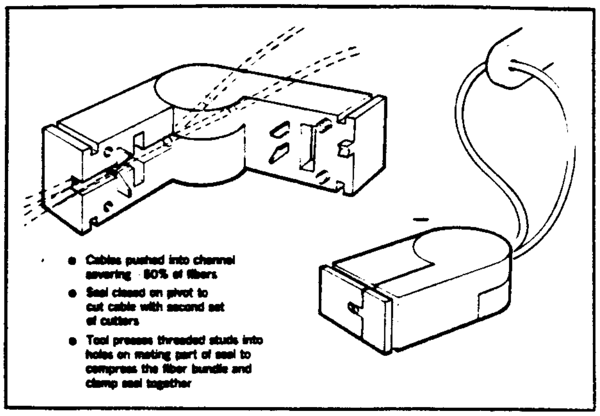


Figure 5: Fiber Optic Seal

guide. Reflected light from the surface of the fiber is blocked by a crossed polaroid. However, light which has traversed a fiber has its plane of polarization rotated and is, therefore, detected.

The camera operation is automatic. The photographic process begins when the seal engages the image guide. The Polaroid SX-70 film records the seal pattern and the seal serial number. When the seal is to be verified, it is rephotographed and the new photograph is compared with the one taken when the seal was installed. Comparison of photographs may be positive-positive or positive-negative.

Research and development on electronic verification of fiber optic seals is directed to practical ways of image generation and electronic pattern recognition. These must be implemented reliably in small portable equipment. Evaluation of signal processing techniques and special designs indicate it is possible to store seal identity without using large amounts of digital memory. Correlation coefficients and moment invariants both appear to be attractive processing techniques.

Ultrasonic Seal

A low cost general purpose ultrasonic seal which can be verified in situ was investigated. Measurement is made by a multi-element piezoelectric transducer array with electronic pattern recognition of the ultrasonic waveforms. Tamper detection is also enhanced through passive design features. Studies and experimentation included 1) investigation and selection of materials for the seal body, 2) analysis of seal designs, 3) evaluation of

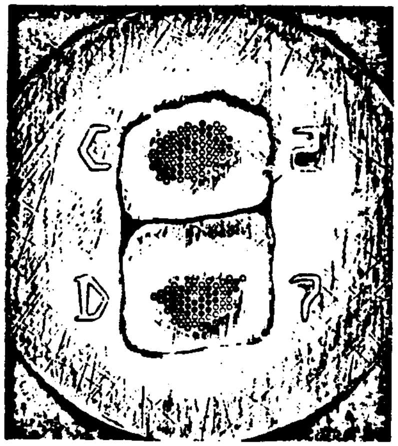


Figure 6: Fiber Optic Seal Identity Pattern

ultrasonic coupling techniques, and, 4) preliminary evaluation of pattern recognition methods. Although seal development was not complete, most of the key elements of this seal system have been demonstrated.

FUEL ASSEMBLY IDENTIFICATION DEVICES

The seal being developed is intended to monitor, during the entire fuel cycle, the inherent uniqueness of a fuel assembly and detect viable access route entries to the fuel. Sandia National Laboratories has extended the CEC/JRC, Ispra, Italy, ultrasonic concept to U.S.-type fuels. Certain portions of the work are subcontracted to Exxon Nuclear to assure compatibility between seal, fuel design, and fuel handling. The BWR seal, called the Fuel Assembly Identification Device (FAID), can be

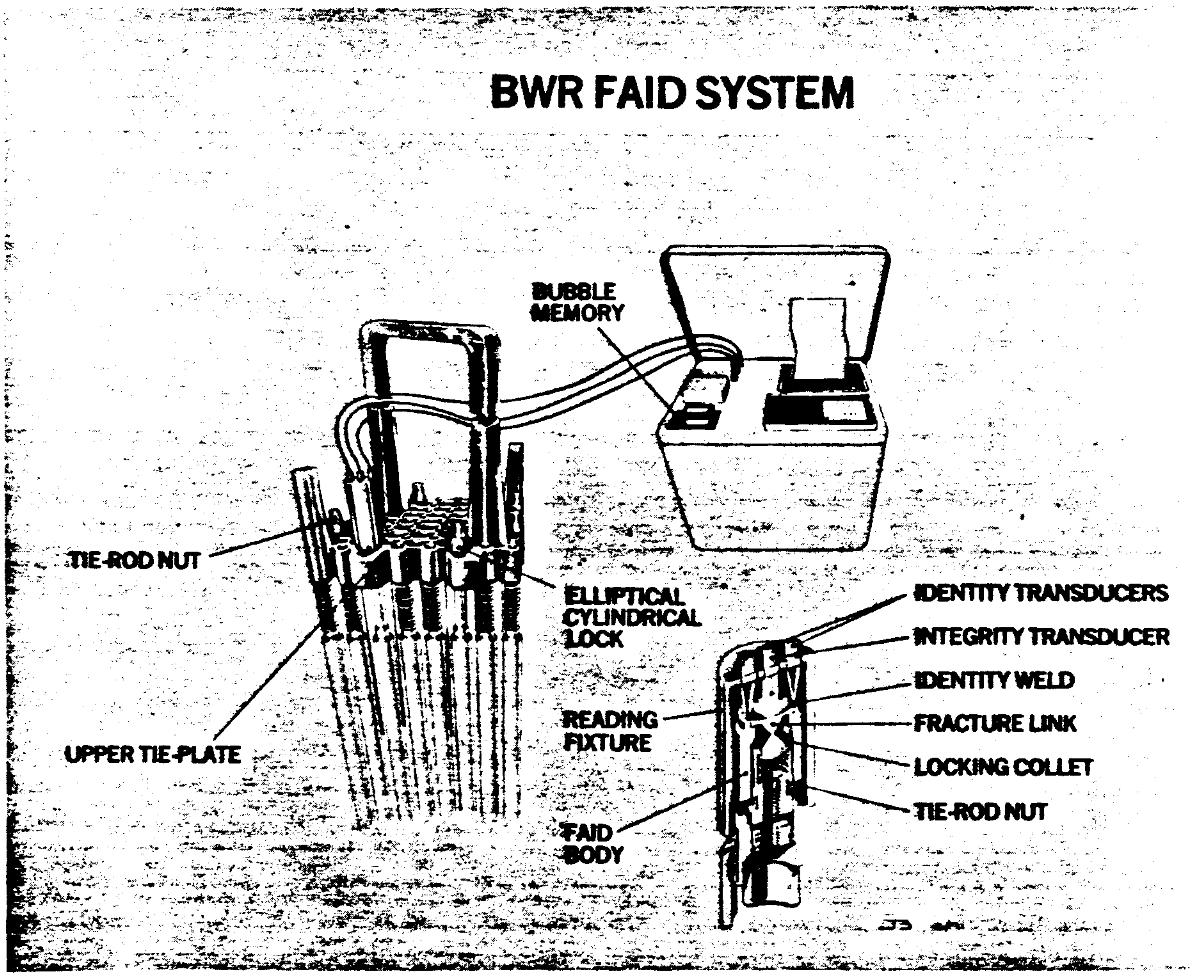


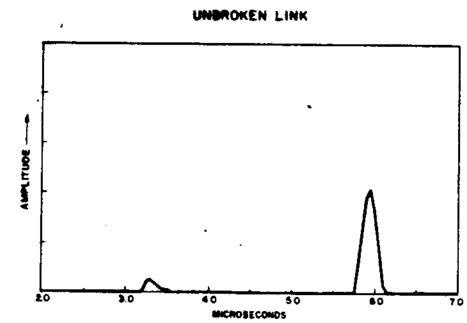
Figure 7: BWR FAID System

attached to a fuel assembly at the fuel fabrication plant and remains with the assembly throughout its lifetime.

The Sandia/Exxon Nuclear BWR FAID system, Figure 7, involves a uniquely identifiable seal which is irreversibly altered when the fuel is accessed via the upper tie-plate. In the Exxon Nuclear fuel assembly design, the upper tie-plate is easily removed by depressing it and turning 8 locking elliptical cylinders through 90°. Once the upper tie-plate is removed, fuel pins may be withdrawn. However, the FAID must first be removed to gain access to the locking cylinder it controls. This removal irreversibly alters it. Figure 7 shows a cutaway of the FAID. Its installation requires replacement of the normal tie-rod nut by a special tie-rod nut with a locking collet. This is the only change required to the fuel assembly. A fracture link is welded into the body of the FAID. When the FAID is installed on the assembly, the lower part of the fracture link irreversibly engages in the locking collet of the tie-rod nut. Removal of the FAID to gain access to the elliptical locking cylinder breaks the fracture link. Part of the FAID protrudes into the upper tie-plate and this prevents removal of the FAID by unscrewing the tie rod nut together with the FAID.

As shown in Figure 7, the seal is interrogated ultrasonically by three 10 MHz transducers. A water coupling is required between the transducer and the seal. For interrogation at the fuel fabrication facility and in the dry area for new fuel storage at the reactor site, water is introduced into the region between the FAID and the reading fixture. The center (integrity) transducer when pulsed gives a plane wave of ultrasonic energy of about 5 cycles. The concave surface of the fracture link reflects a pulse back to the transducer and simultaneously focusses the transmitted pulse into the neck of the fracture link. After passing through the neck, the transmitted pulse diverges to reflect normally from the convex surface. It then passes back through the neck and becomes a plane wave at the concave surface. The total transit time for the pulse is about 70 μs - 64 μs in water and 6 μs in the fracture link. The reflected pulse from the concave surface acts as a fiducial mark for the wave traversing the fracture link. Figure 8 shows the absolute value, somewhat smoothed, of the ultrasonic pulse (a) from an unbroken $\overline{B}$ link and (b) from the broken B link. The temporal distribution of the ultrasonic energy for the two cases is very different. The disposition of the fracture link is thus easily determined. Our method of comparing signals and hence establishing the disposition of the link is to calculate the correlation coefficient between the sample signal and a standard signal, either B or $\overline{B}$.

The outer (identity) transducers are 10 MHz 5-cycle pulsed transducers focussed to a 2 mm diameter with about a 2 mm depth of focus. They interrogate the fracture link-to-case weld. This weld is made intentionally bumpy to inhibit the strong reflection from a flat surface. Thus, the transducers sample the surface and about 2 mm into the surface of the weld. The reading fixture is keyed to the FAID to position these transducers on subsequent readings within the error of placement



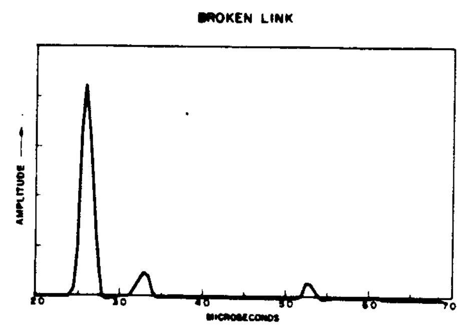


Figure 8: FAID Integrity. Smoothed absolute value to a 10 MHz response to

(a) an unbroken fracture line

(b) a broken link

(Fiducial mark starting at t = 0 not shown.)

over the same weld region. Figure 9 shows the signals from two different weld regions. Again the correlation coefficient is used to establish the similarity or dissimilarity of the signals and hence to identify a weld region.

Figure 10 shows the cumulative density functions, cdfs, of the correlation coefficients for a number of cases. Curve A is the cdf of the correlation coefficients comparing different weld regions. This is equivalent to comparing the same geometric weld position on different FAIDs. The probability density function, pdf, is not inconsistent with a normal distribution and in our experiments had a mean, $\bar{r}$, of 0.1 (instead of 0) and a standard deviation, σ, of 0.17. For a normal distribution, the probability of obtaining a variate value deviating from the true mean by 3 standard deviations is about 0.1% or $Pr(r - \mu) > 3\sigma \simeq .001$. Suppose $r < .5$ defines different FAIDs and $r > .5$ as a subsequent

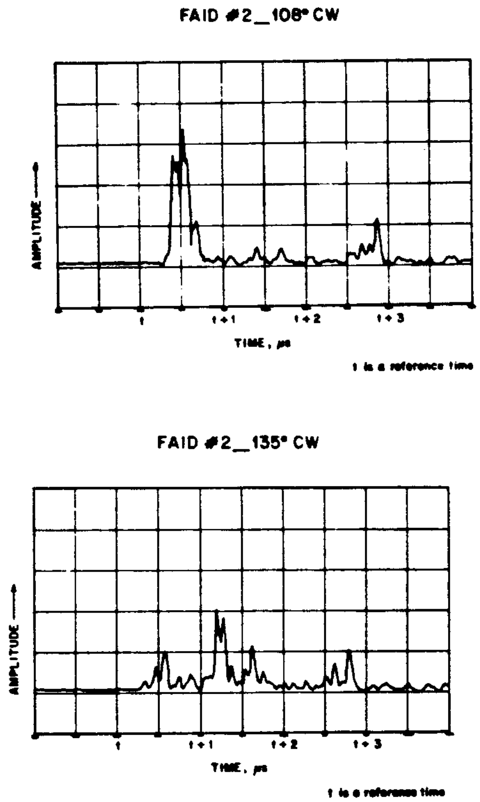


Figure 9: Identity traces at two different angular positions of the same FAID.

reading of the same FAID. Then we would be wrong about 0.1% of the time saying we have the same FAID when indeed we obtain a high r when comparing two different FAIDs. This experiment establishes a FAID identity from one weld region as unique to 1 in 10^3, or 1 in 10^6 for two weld regions or two identity transducers.

As yet the analytical form of the pdfs of the correlation coefficients when comparing subsequent readings of the same weld region of the same FAIDs have not been established. However, some comments are appropriate. If the same transducer is used for the subsequent measurements, the correlation coefficient has a lower bound of about 0.95. If a different transducer is used, the correlation coefficient degrades and has a lower bound of about 0.87. These cases are illustrated by curves B and C. The exact form of curves requires more experimental data. However, clearly using the weld and calculating correlation coefficients adequately resolves between the same and different FAIDs.

The objective of seal readout in the field is to compare the identity and integrity signatures of the seal with previously determined and stored information. The identity

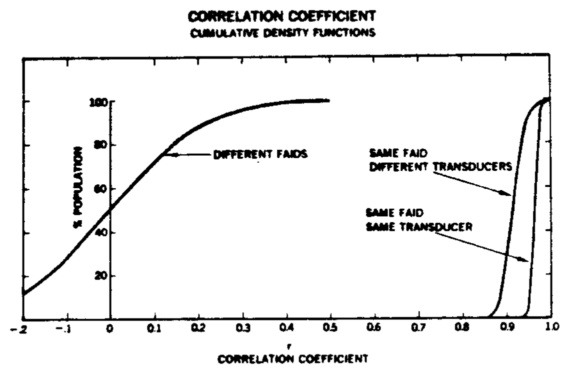


Figure 10: Cumulative density functions of the correlation coefficient when comparing different FAIDs (Curve A) and comparing the Same FAID with the same transducer (Curve B) and with a different transducer (Curve C).

information is carried in a bubble memory cassette by the inspector for comparison with the signature found in the field. A block diagram of a prototype instrument to perform both reading and comparison functions is shown in Figure 10. The instrument is interactively controlled by an MC 6800 microprocessor

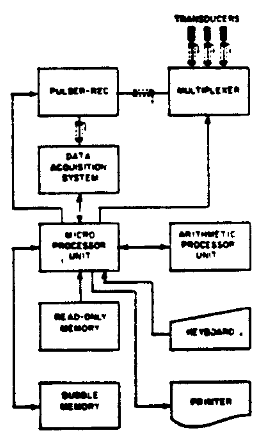


Figure 11: Electronic Block Diagram of FAID reader.

which guides the operator through the seal verification. Information, such as serial number, identity patterns of a number of fuel assemblies, and their actual locations in the storage pool is contained in the bubble memory. The 1/4 megabit bubble, based on two FAIDs per assembly, contains the information on 30 fuel assemblies. The keyboard enables the operator to respond to questions and enter information such as serial numbers. Output is via a small thermal printer.

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