Commission of the European Communities

nuclear science and technology

VAK III
seals and sealing system

Report
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ABBREVIATIONS AND ACRONYMS

F.A.	Fuel Assembly
KWU	KraftWerk Union (FRG)
VAK	Versuchsatomkraftwerk (Kahl)
CRT	Cathode Ray Tube
LWR	Light Water Reactor
PWR	Pressurized Water Reactor
BWR	Boiling Water Reactor
VAK III	Seal series from JRC
JRC	Joint Research Center (Ispra)
MEI	Internal External Markings
MEI b	Same system with a lower fracture link
DOBRIC	Double Breakage Integrity Check
RELOC	Reinforce Locking device
STRID	Strong Random Internal Defects (base of the VAK III Seal and Sealing System)
VAK 45	Name of the new JRC Compact Instrument

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REF 2 : "STUDY AND DETERMINATION OF A SPECIAL INTERMEDIATE BUSHING TO BE USED AS A DISTANCE PIECE WHEN EXXON F.E. WILL BE SEALED WITH VAK 2 SEALS"
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REF 3 : "RECENT PROGRESS IN THE F.A. SEALING PROCESS DEVELOPED AT JRC ISPRA (VAK III) AND RESULTS OBTAINED DURING THE LAST DEMONSTRATION AT THE KAHL EXPERIMENTAL NUCLEAR POWER STATION"
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1. INTRODUCTION

Since October 1983, a new version of the VAK Seal has been proposed by JRC Ispra as a possible solution for the sealing of BWR (and PWR) Fuel Assemblies.
Demonstration campaigns at the Kahl Facility (FRG) took place in several occasions (October 1983, May 1984) and other ones are being prepared for October 1984 and May 1985.

The new version is called VAK III and presents similitudes and differences with respect to the previous concept (VAK I and VAK II).
It is similar in shape and dimensions, it is installed on the same extended tie-rods and the same tools and procedures are to be used during the clamping or extraction operations.

It is different from the previous versions because of its internal identification marking process which provides now Strong Random Internal Defects (STRID) and also because its integrity status can be controlled through the breaking of its internal grip, during the extraction operation. The grip status is obtained ultrasonically and gives, by turn, the integrity status. It is called Double Breakage Integrity Check (DOBRIC). It is also provided with a Reinforced Locking device (RELOC) to obtain a safer clamping while installed on an extended tie-rod of the F.A.

Corresponding to attempts to increase the marking quality and to reduce the seal's length, we have studied three presentations of the VAK III seal which are called:

1rst presentation:	VAK III MEI	Length:	42 mm	Oct 83
2nd presentation:	VAK III MEI b	Length:	37 mm	May 84
3rd presentation:	VAK III MEI a	Length:	34 mm	May 85

The MEI b is the type we will install in October 1984.
MEI is the abbreviation for Marquage Externe Interne which characterizes the way the STRIDs are obtained into the seal.

It is obvious that the VAK III Seal and its related Sealing Process, along with the Identification and Integrity Check techniques we describe in this report represent a whole feasibility and real-scale study. Apart from the basic original characteristics of that kind of sealing technique, i.e. STRID and in some extent DOBRIC and RELOC, most of the features are flexible and could be modified while working on pre-industrial series. In particular the existing tools work properly for demonstration purposes but could easily be simplified in the future. We will try to underline such points when alternative solutions are easily conceivable.

2. GENERAL DESCRIPTION

The VAK III Sealing System has been mainly developed for the safeguarding of LWR Fuel Assemblies such as KWU and Exxon ones, in use at the Kahl facility.
Nevertheless, the VAK III System can be applied to other Fuel Assemblies which are normally disassembled by removing the upper grip upwards, while repairing or changing some pins of the bundle.

2.1 Basic functions

The VAK III Sealing System provides three basic functions, considered as essential in the Safeguards analysis.

i/ It locks the upper grid of the Fuel Assembly under protection, impeding its disassembling without a previous breakage of the seal (Locking Function).

ii/ It gives a Unique Random Identity to the F.A. and offers a technique to distantly verify it (Identification Function).

iii/ It offers the possibility to check distantly the Integrity Status of the F.A., through the checking of the Seal Integrity (Integrity Check Function).

Note a): The basic concept consisting in separating the Identification and Integrity Check functions, as in the present solution, can be discussed. A system with these two functions in one is also conceivable.

Note b): By Integrity Status, we mean "Intact" or "Not intact" which is for saying that the F.A. (thus its seal) hasn't been dismounted or attempted to dismount or, on the contrary, dismounted or attempted to dismount.

Note c): From the beginning the VAK System uses special breakable extended tie-rod ends, according to a former Ispra drawing. These ends are fitted to the tie-rods at the fabrication plant which represents an inconvenient.
We go on using the existing special ends provided with the Exxon F.A. available at Kahl. For the future, we envisage to minimize the intervention at the fabrication plant.

2.2 Operating functions

The VAK III Sealing System takes into account the requirements from the Inspection and Operator sides. It also embodies different sub-systems aimed at the performance of necessary operating functions such as:

iv/ Installing the seal on a fresh F.A. (Positioning Function, Dry)

v/ Installing the seal, in the pool, on an immersed irradiated F.A. (Positioning Function, Wet)

vi/ Extracting the seal, in the pool, from an irradiated F.A. (Breaking Function)

vii/ Identifying the seal, in the pool, on an immersed irradiated or fresh F.A. (Identity Measurement Function)

viii/ Identifying the seal, in dry conditions, on a fresh F.A. (Identity Measurement Function, Dry)

ix/ Checking the Integrity Status of the seal and obtaining a record of it, the F.A. being immersed in the pool (Integrity Measurement Function).

x/ Processing the data obtained from the Identity Measurement Records either in a visual comparison of the obtained graphs or by an Automatic Correlating Process. (Signature Identification Function)

Note d): Checking the Seal's Integrity in dry conditions is feasible but not considered as essential at the moment.

Note e): Grouping the Identity and Integrity Measurement Functions in one, by using in particular a unique tool has been contemplated. Nevertheless, at the demonstration level we have preferred using separate tools.

Note f): The Breaking Function involves, in our case, the demonstration and the measurement of the breaking forces, which would not be required in routine use. Thus the possible simflification of the tool.

Note g): Functions vii, viii and ix are different from functions ii and iii, the later being related to the existence of the Integrity and Identity and the former to the ways to check them. They are, indeed, very much interrelated.

2.3 Seals, Operating Tools and Instrumentation

In order to meet properly the requirements of the Basic Functions (see: 2.1) and the ones of the Operating Functions (see: 2.1) the VAK III System includes three different equipments. The seals are consumable material. The tools normally stay in the Reactor site. The instrumentation is transportable according to the Inspection requirements.

2.3.1 The Seals

In the whole system, the seal represents the most important item. It has been designed to fulfill the Basic Functions.

Locking Function (i/) :

a. KWU F.A. : It is obtained by simply clamping the seal on the corresponding extended tie-rod. Thus the upper hexagonal nut of the F.A. cannot be unscrewed without breaking the seal (and the tie-rod extension)

b. Exxon F.A. : To obtain the locking function, due to the special locking mechanism used by Exxon on its upper tie plate, a Special Bushing has to be mounted on the tie-rod extension prior to clamp the seal. The piece and the way it is fitted to the F.A. are very simple.

Identification Function (ii/) :

The seal is provided with ultrasonically detectable STRIDs (STrong Random Internal Defects) embodied in the upper part of the shell in a permanent manner, by means of a special brazing process. These defects have to be read by an external transducer belonging to the measuring tool.

The random distribution of the defects into the seal is such to offer a permanent characteristic to each single seal. That characteristic results in a stable signature delivered by the reading instrumentation each time the seal is interrogated. It is expected that a unique character is conferred to each single seal. Thus the question about the seal is transferred to the question about its signature.

Integrity Check Function (iii/) :

The seal embodies in its lower half a gripping mechanism which first purpose is to clamp the seal onto the extended tie-rod of the F.A., in an irreversible manner.
Breaking (or extracting) the seal means pulling the seal upwards with a breaking tool so that, under a certain force, the rod extension is broken and the F.A. can then be normally disassembled.
The second purpose of the gripping mechanism is to indicate whether the seal has been pulled or not. During the extraction of a seal, the grip inside the seal is pulled and undergoes an increasing tension which breaks the grip before the tie-rod. Thus a Double Breakage Integrity Check (DOBRIC) makes it possible to verify that the seal has never been extracted before. The status of the grip inside the seal is easily verified ultrasonically. Thus the status of the seal is known (extracted or not extracted) and consequently the status of the F.A. (not intact or intact).

Note h): To make the gripping mechanism safer and properly closed on the neck of the extended tie-rod during the breaking operation, it is provided with a REinforced LOCking device (RELOC) which is useful either for the Locking Function or for the Integrity Check Function.

Note i): The DOBRIC concept is directly related to the use of extended breakable tie-rod ends as on the existing F.A.s, available at Kahl. It could be kept or, on the contrary, eliminated in a sealing system without breakable extended tie-rod ends.

2.3.2 The Operating Tools

Tools are necessary to place or extract the seals but also to check them for the purpose of inspection. They are normally operated in the Reactor pool, partly immersed in water, while the F.A. under consideration has been installed on a conventional stripping-machine at about 4 meters under the water level.
Furthermore, various conditions can be requested as for the position of the F.A. For instance, in the dry storage or in the wet storage positions. These conditions would lead to some change on the existing tools (lengthening or tightening of the sub-systems) but would not change the concept of the VAK Sealing System.
According to their use we separate the Operating Tools in Handling Tools and Measuring Tools.

The Handling Tools

Positioning Function (v/) :

The Positioning Tool is a simple aluminium extendable tube, about 5m long. Its lower extremity has a gripping mandrel which can be open or closed by the operator, rotating counterclockwise or clockwise an handle located at the upper extremity.

Note j): The Positioning Function (iv/) in dry conditions can be done directly by hand on fresh F.A.s. staying in the dry storage bay. A light hammer facilitates the clamping of the seal on its tie-rod extension.

Note k): If an Exxon F.A. is to be sealed, the same Positioning Tool is used to place the Special Bushing before the seal.

Breaking Function (vi/) :

The Breaking Tool is an heavier one. It embodies a traction mechanism capable of giving and measuring forces up to 3,000 N. Its measuring device has been used only for demonstration and licensing tests. It is not an actual measurement tool. It is provided, too, with a lower mandrel for the seizing of the seal shell and also with a reaction claw shaped fork which is supported by the Special Bushing (Exxon F.A.) or by the nut (KWU F.A.) during the extraction operation. While rotating the upper end, with a wrench, the operator obtains the first breakage at about 1,300 N and the second breakage at about 2,600 N . These two breakages are clearly felt by the operator.

Note l): After a seal has been extracted from an Exxon F.A. the corresponding special bushing is removed with the positioning tool (see note k).

The Measuring Tools

These tools allow the performance of checking the identity or integrity of a seal, irrespective from the need for placing or extracting it.

Identity Measurement Function (vii/) :

The Identity Tool is the most important tool. It has been designed according to the very concept of the VAK III Seal. Its lower extremity has a revolving mechanism which makes it possible the rotation of an eccentred transducer around a 3 or 3.5 mm radius circle, so that the upper part of the seal can be ultrasonically explored during one revolution. The transducer is connected to the ultrasonic instrument

which follows the fluctuations of the echoes given by the random internal defects (STRIDs), while the transducer is moved with respect to the seal.
The transducer is part of the Instrumentation and is removed from the tool during the resting periods.

Note m): The Identity Tool is extendable. In its short configuration (about 0.5 m length), it can be used as a Dry Identification Tool (see below). It can also be lengthened in order to be used on F.A.s located in the wet storage. This last configuration has not been tested at the moment.

Identity Measurement Function: Dry (viii/) :

The Dry Identity Tool provides the same function as the Identity Tool, but it has been modified so that it can fit a seal on a fresh F.A. with no necessity of immersion. It embodies a small tank, filled with water, so that the ultrasonic coupling between the seal and the transducer can be obtained with no bubbles. Its revolving system is the same as for the normal Identity Tool. It would allow to safe time during the sealing of fresh F.A.s either in the reactor or at the manufacturer plant, before the F.A.s are shipped.

Integrity Measurement Function (ix/) :

The Integrity Tool is a very simple and light tool. It is a long tube, about 4.5 m long which fits - at its lower extremity - to the seal to be checked. It brings a transducer proximate to the seal so that its integrity can be checked ultrasonically. It is connected to the same ultrasonic instrument which was used for the Identity Measurement.

During an Integrity Check is performed, the transducer is located above the seal, axially, at a distance of 15 mm. This transducer is removed, too, during the resting periods.

Note n): Owing to their simplicity, the two tools: Positioning Tool and Integrity Tool could be fused in one single tool performing the two different functions (v/ and viii/).

2.3.3 The Instrumentation

The Instrumentation is important because it is essential to the measurement and the eventual recording of the signatures given by the seals.

A difference exists between the Instrumentation which has been used for demonstration purposes and the Instruments which would be part of the Inspector Equipment.

The functions covered by the Instrumentation are:

a. The Breaking Function (vi/)

b. The Identity Measurement Functions (vii/ and viii/)

c. The Integrity Measurement Function (ix/)

d. The Signature Identification Function (x/)

Breaking Function (vi/) :

While performing the extraction of a seal, the measurement of the forces under which the internal grip breaks (1rst breakage) and then the extended tie-rod (2nd breakage) occur are an indication of the Integrity Status. Nevertheless, this measurement is not necessary because the operator performing the extraction can easily feel the two breakages (DOBRIC).
Strain gages are permanently installed in the Breaking Tool. They are measured by a Wheatstone Bridge Instrument and the resulting Traction Force can be recorded on a chart recorder or simply read on a digital voltmeter. The forces necessary to break the fracture links are determined by their respective sections (see: 2.3.2 Breaking Function).

Identity Measurement Functions (vii/ and viii/) :

In the VAK III Sealing System, the signature of a particular seal is obtained as an output of the ultrasonic instrument (SONIC FTS MARK I) which fluctuates as the Identity Tool rotates. As a fluctuating voltage, it can be recorded during one or more revolutions:

a. on a Chart Recorder, thus immediately visualized

b. on an Analog Tape Recorder to store the data

c. on a Computer Memory thus making it possible a further data processing for the purpose of comparing two signatures.

As far as visual comparisons are acceptable, the graphs obtained on the x(t) paper recorder are sufficient to let the inspector make up his mind while comparing two signatures.
If, on the contrary, an automatic identification is requested, the same signature as on the chart recorder has to be data processed, so that the calculation of (for instance) the Correlation Coefficient between two signatures can be done (see below).

Note o): For the purpose of the demonstration, a Desk Computer has been used until May 1984. A minicomputer is now being associated with the ultrasonic instrument to obtain a transportable Compact Instrument, more suitable to the Inspection.

Integrity Measurement Function (ix/) :

The Ultrasonic Instrument used with the VAK III Sealing System (SONIC) is equipped with a CRT, which allows the Operator to control and check the signals coming out from the Transducer. The Integrity Signal given by the seal presents a very simple shape and is easy to observe. They are two peaks (or two peak zone first edges) to watch. The first corresponds to the fracture link at 15 mm from the Seal upper surface; and the second, to the fracture rod bottom (see: pages 11 and 13), at 23 mm from the top. The First peak is generally smaller than the Second one which, by turn, is higher and sharper than the first one. In the intact situation, the two peaks are present. In the broken situation, the second peak vanishes complely and the first peak is still there even with a slightly modified aspect, because of the link deformation prior to the breakage.

Signature Identification Function (x/) :

The fundamental requirement of a Sealing System is to provide the Inspector with a stable, random and re-measurable Signature each time he is checking a determined seal (basic Identification Function ii/ as in 2.1 above). Thus, he can relate faithfully a unique signature to a unique seal.

A corollary to this statement is that the Sealing System has to be associated to a Comparison Means allowing the Inspector to perform the Signature Identification Function

Three possibilities are offered involving different degrees of sophistication to perform the Signature Identification. Different instruments can be used simultaneously (redundancy) or separately.

a. Use of a simple x(t) paper recorder giving a graph each time the signature is interrogated and compare visually the graphs.

b. Record the output signal on an Analog Cassette and transfer that signal either again on the paper recorder or to a Desk Computer which digitizes the signal into a series of (for instance) 250 values and stores it in its own memory or transfers it on an auxiliary digital memory. The comparison between two different series is made by calculating the Coefficient of Correlation (or Bravais-Pearson Coefficient) which theoretical value must be between -1 and +1; a value reasonably proximate to +1 indicating that the two signatures under comparison come from the same seal.

c. Directly record the analog output signal coming from the Ultrasonic Instrument in a Portable Mini Computer through a special Analog/Digital acquisition Unit connected with the Mini Computer. The peripherals units, such as an auxiliary Digital Cassette Memory and a Printing Device can complete the Mini Computer functions, so that the Correlation Coefficient calculation and/or its results can be presented on paper strips. The Identity Tool can also be controlled by the Inspector from the Mini Computer according to a pre-established program.

Note p): The calculation of the Coefficient of Correlation between two series of values represents one among other possible criteria. The flexibility of a modern Mini Computer is such as to allow the performance of different calculation process.

Note q): The c. solution allows that all the instrumentation necessary for performing the the Identity Taking of one seal and its eventual Identification be compacted in one single box we use to call " Compact Instrument "

Note r): The instrumentation as in point b. has been mainly used by JRC Ispra during the laboratory tests and demonstration campaigns at Kahl. Once the whole feasibility of the system has been proven, the instrumentation as in point c. has been studied in order to propose a transportable and more practical Compact Instrumentation to the potential Inspector.

3. SEAL DESCRIPTION AND LOCKING FUNCTION

3.1 Seal constitution and characteristics

Refer to drawings 84-1263-OA and 84-1263-OB given in Annex I

The seal is a cylindric body with a flat upper end and a hollow lower extremity in which the tie-rod extension penetrates when the seal is being clamped on it.
The hollow part is a cylindrical room about 10 mm diameter containing the gripping mechanism and a spring which purpose is to keep the seal steady once it has been clamped on the F.A. tie-rod extension.

The lower extremity of the VAK III Seal is a narrower section which gives passage with precision to the extende tie-rod collar (see: drawing 84-1263-OB) when the seal is being clamped on the F.A.
Furthermore, this tapered section presents an external neck (flat or conical according to the versions) which allows the seizing of the seal by the Breaking Tool during the seal extraction.

The gripping mechanism comprises : (see 84-1263-OA)

- one elastic grip with six jaws........... part nb 6
- one helicoidal spring.................... " " 5
- one thrust cup........................... " " 3
- one locking ring......................... " " 4

The grip is connected to the upper part of the seal by means of:

- one fracture rod......................... " " 7

which is screwed and blocked into the grip at its lower extremity and embedded into the upper part by brazing. The neck - or fracture link - of that rod is the basis of the Integrity Check

The upper part of the seal - or Identity Zone - is made of a cylindrical room filled with:

- 5 or more slotted disks................... " " 8

which are stacked in the shell, in a random orientation,

during the fabrication process, before to be squeezed by the:

- lid....................................... " " 9

and brazed into the:

- seal body................................. " " 1

In the VAK III MEI b presentation the seal is closed, after the brazing process, by means of an electron beam welded :

- bottom part............................... " " 2

Parts nb 1,2,3,7,8 and 9 are made of Stainless Steel 304 L

Parts nb 4 and 6 are made of hardened Inconel X 750

Part nb 5 is made of special Stainless Steel for springs.

The last VAK III MEI b Seal is 13 mm O.D. 37 mm height and has a weight of about 30 grams .

3.2 Clamping the Seal on the Tie-rod

Refer to drawing 83-1250-12 in Annex I and scheme below.

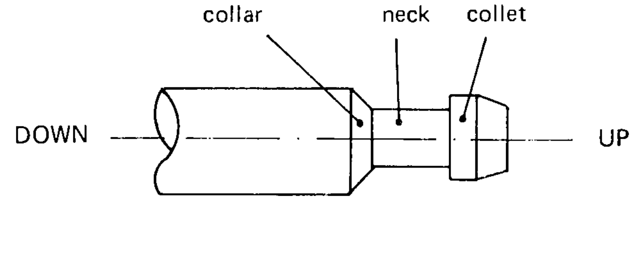
The clamping of the Seal on the Extended Tie-rod is such as to make it impossible that the Seal be extracted without breaking the tie-rod extension.

The following steps of the clamping operation are illustrated schematically on drawing 83-1250-12.

- Step 1 : The seal is pushed down up to the first contact between the tie-rod collet and the elastic grip (part nb 6 of the seal)
- Step 2 : As the seal is pushed down further, the tie-rod collet opens the jaws of the elastic grip
- Step 3 : Up to the second contact between the tie-rod collar and tapered bottom of the thrust cup (part nb 3)
- Step 4 : Down further, the compression of the spring (part nb 5) starts and the third contact, between the grip and the locking ring (part nb 4), occurs while the grip reaches the locking level with respect to the tie-rod neck.
- Step 5 : Down further, while the helicoidal spring is more compressed, the elastic grip closes on the tie-rod neck
- Step 6 : Down further, the tapered extremities of the jaws (of the elestic grip) open the locking ring which is elastic
- Step 7 : Down further, the jaws seize the locking ring in their external groove
- Step 8 : The pressure is released the seal moves upwards as the spring decompresses partially. The grip goes up back to the tie-rod collet while the locking ring is wedged in between the grip's jaws and the thrust cup, thus reinforcing the locking safety of the grip which is already elastically clamped on the tie-rod head (RELOC)

Note s): The compression stroke is only of 5.5 mm

Note t): The figure given here is for clarity of terms concerning the tie-rod extension (head)



3.3 Locking Function and Breakage of the Seal

Refer to: drawing 84-1263-0C in Annex I
: " 84-1263-0B in Annex I
: " 84-1263-0A in Annex I
:fig. 1 below (next page)
:fig. 2 below (next second page)
:reference /1/ (different figures)(*)(given in Annex IV)
:paragraphs 2.1 and 2.3.1 above

After the VAK III Seal has been clamped on the tie-rod extension (we recall that this extension could be transferred on a special nut in another possible presentation of the VAK III Sealing System :see fig. 2 (f) in ref /1/) the dis assembling of the Upper Tie Plate is made impossible without breaking (extracting) the seal .

In the KWU F.A., this would be obtained simply because the hexagonal nut of the tie-rod cannot be unscrewed (see fig. 1 in /1/) The locking function is the same as for the first VAK I Seal.

In the Exxon F.A.,"the Upper Tie Plate is normally removed by pushing it downward against the fuel rod compression springs, rotating eight elliptically shaped locking sleeves 90° and allowing them to pass through elliptically shaped holes in the tie plate" says a detailed description by R. Nilson from Exxon.(see fig.1 and fig.2). Once the Bushing (or Special Bushing as described in /2/) has been placed, its two lower legs"extend into the elliptically shaped hole in the tie-plate, preventing the rotation of the locking sleeves (elliptical sleeves), even with the Tie Plate deppressed against the compression springs". The Special Bushing must be removed to unlock the tie plate and the Seal must be broken to remove the Special Bushing.(see also drawing 80-1174-06, Annex I)

The breakage of the seal can be schematically described as follows (see fig.3 or drawing 84-1263-0C)

- Step 1 : The Breaking Tool is in position, with its claw shaped fork in contact with the upper part of the bushing (or of the hexagonal nut in KWU configuration); the Seal has been seized by the mandrel which starts being pulled upwards.
- Step 2 : The fracture link of the Fracture Rod (part nb 7 on drawing 84-1263-0A) is strained by the traction force exerted on the seal's body and lengthens.
- Step 3 : The Fracture Link of the Fracture Rod (part nb 7) breaks so that its broken bottom, together with the grip is projected downward until the rod's bottom end touches the tie-rod head.

(*) "Recent Practical Safeguards Experience with the new Version of the LWR (VAK) Seal" B.C.d'Agraives et al.

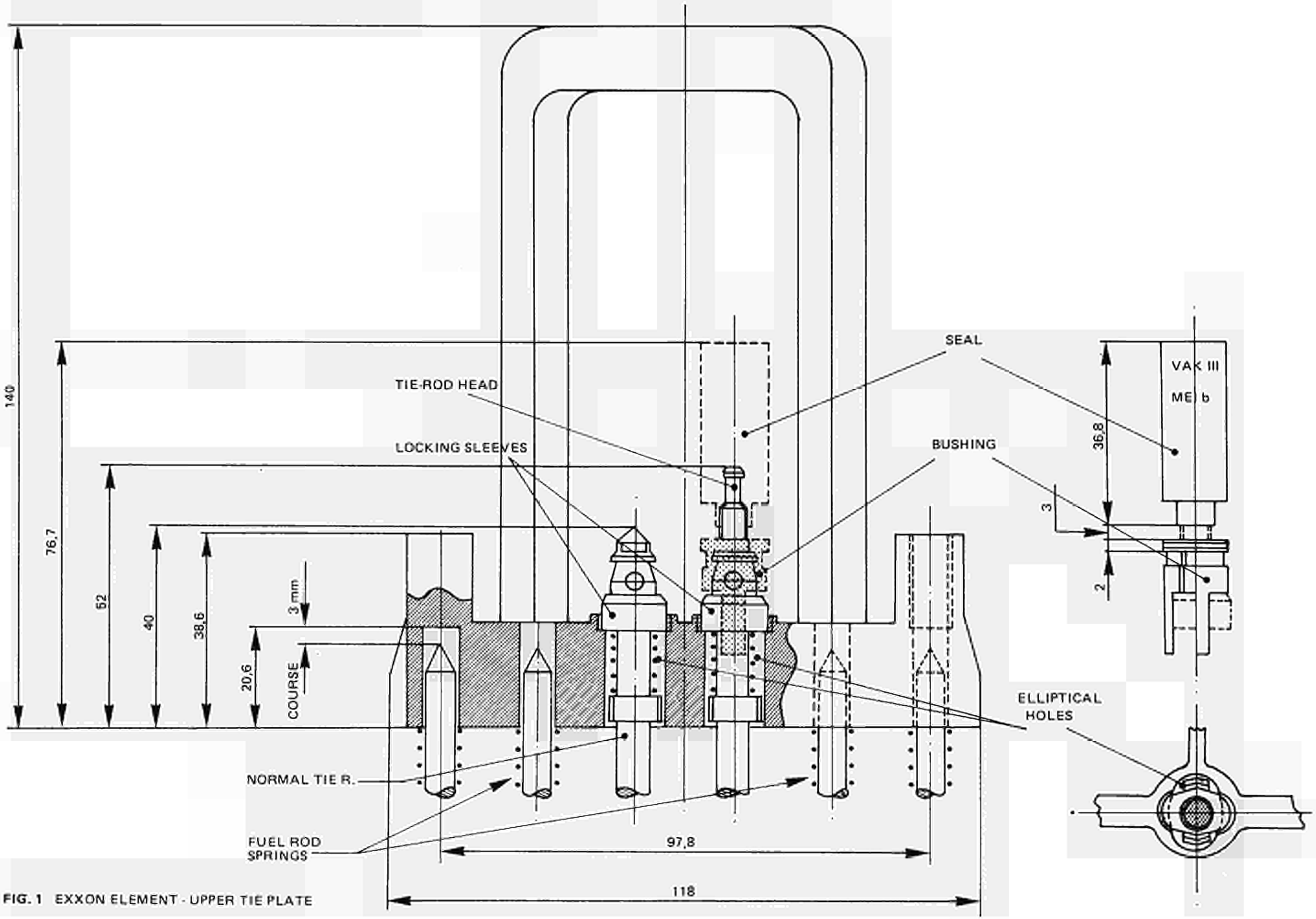


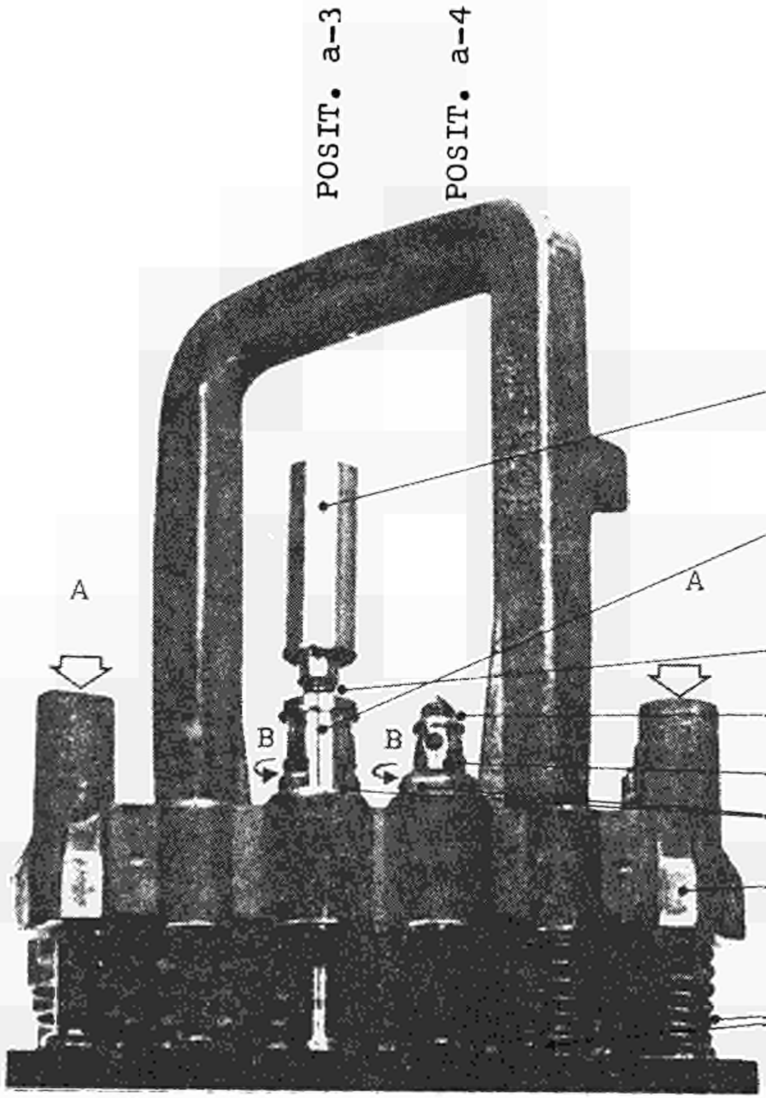
FIG. 1 EXXON ELEMENT - UPPER TIE PLATE

Note: To remove the Upper Tie Plate
from the F.A. without Seal on

a) Press down the Tie Plate (about 3mm) in "A" with a total force of about 500N

b) Rotate the 8 Locking Elliptical Sleeve 90° in "B"

c) Release the pressure on the Tie Plate



VAK III MEI-b SEAL	(JRC)	(normally in pos. a-4 (or b-1 or f-3)
SPECIAL BUSHING (with two legs) (weight: 5.5 g) (extr.force:50N)	(JRC)	(placed on the normal nut, before the seal is clamped)
EXTENDED TIE-ROD	(Exxon upon JRC drawing)	
NORMAL TIE-ROD	(Exxon)	
NORMAL NUT	(Exxon)	
ELLIPTICAL SLEEVES	(Exxon)	
TIE PLATE BASE	(Exxon)	
FUEL ROD SPRINGS	(Exxon)	

Note: on that dummy the normal tie-rod and the extended one have inverted positions.

FIG. 2: DUMMY OF AN UPPER TIE PLATE (EXXON F.A.)

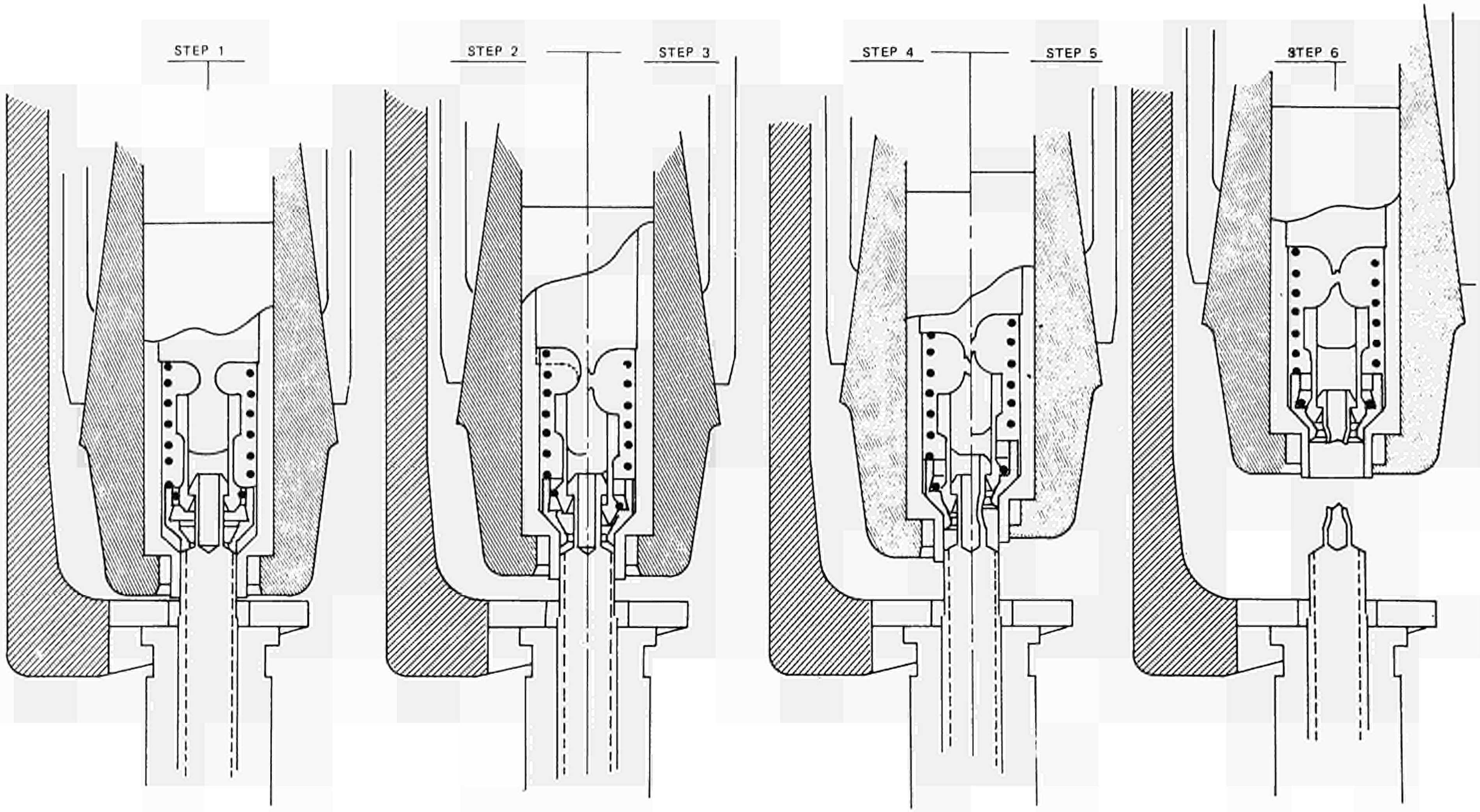


FIG.3: Six spets of the breakage of the VAK III MEI Seal
(see also drawing 84-1263-0C)

- Step 4 : As the seal is pulled further upwards by the Breaking Tool, the Thrust Cup (part nb 3) is also pushed upwards up to a position where the jaws of the grip enter and fit the conical internal part of the cup. Thus the jaws are wedged between the Thrust Cup and the Tie-Rod Neck and strongly seize the latter while the Seal is pulled further. This is the reinforced locking device of the Seal (RELOC).
- Step 5 : The traction force increases up to about 2,600 N The Tie-Rod Neck lengthens and breaks.
- Step 6 : The Seal is broken ("extracted") and can be removed with the breaking tool. The bushing stays in position because it tightens elastically around the tie-rod nut. It can be removed later on.

Note u): All these steps have a duration of few seconds. Nevertheless, the operator decides at which speed he wants to increase the traction force.
Step 3 occurs at about 1,300 N

4. OPERATING TOOLS

The general description of the Operating Tools of the VAK III Sealing System has been given in the previous chapter. It corresponds to the tools actually existing and being presently used for the demonstration campaigns at the Kahl facility.

A delailed description cannot be given here. Nevertheless, we give, in Annex, the fabrication drawings of the 4 Operating Tools which are sufficient to understand their functionning. We give below a list, in English (we hope), of the parts of the tools, item by item, to ease the understanding.

4.1 Two Handling Tools

4.1.1 The Positioning Tool

Refer to Annex II, Drawing IX-71-918-OC and 2.3.2

It is used for placing the Seal and placing or remove the Special Bushing.

Parts are: (2a)= Tapered Grip ; (3a)=Mandrel ; (4)=Screw; (5)=Guiding Screw; (6)=Spring; (7a)=Tie rod; (8b)=Intermediate tube; (10a)=(12)=Lock-nut; (13)=Connecting tube; (14) =Lock-nut; (15b)=Tie rod; (16b)=Upper external tube; (17b) =Friction bushing; (18b)=Rotating handle

4.1.2 The Breaking Tool

Refer to Annex II, Drawing IX-72-929-OB and 2.3.2

This tool is the transformed version of the first extraction tool studied for the first VAK I and II Seals. It has been modified in 1981 to allow the performance of dynamometric measurements (forces) during the seal breakages.

It is used for the extraction of the VAK III Seal. It is about 4.5 m long. Its weight is estimated about 40 kg in air.

Parts are: (1c)=Traction lead-screw; (2)=Hexagonal nut; (3A)=Friction bushing; (4A)=Sleeve; (5a)=Handle; (7)=Locking sleeve; (8)= Lower external tube; (9a)= Locking screw; (10A)=Tie rod; (11A)=Intermediate tube; (15A)=Handle ring; (18)=Lock-nut; (19)=(20)=(21)=Springs; (22)=Lever; (23)= Pin (24)=Washer; (25)=Upper external tube; (26)=Guiding sleeve; (27)=Eylet screw; (28A)=Upper intermediate tube; (29A)=Washer; (34)=Mandrel; (36)=Locking screw; (37)=Distance-piece; (38a)=Traction sleeve; (41)= Tie rod; (42b)=lid with a square shape to be seized by a square wrehch and rotated; (43)= Handle (recently eliminated); (44)=Guiding sleeve; (45A)= Key; (46)= Rod with triangular section receiving 3 strain-gages for the traction force measurement; (47)=Seizing Grip; (48)=Reaction piece (Claw shaped fork); (49)=(51)=(52)=Screws.

Another light modification - not mentionned on this drawing - has been brought to the tool in 1984, so that the upwards reaction of parts (11A+28A) at the 1rst breakage of the DOBRIC is slowered and keep the grip (47) closed on the seal.

4.2 Two Measuring Tools

4.2.1 The Identity Tool

Refer to Annex II, Drawing 83-1245-OA and 2.3.2

This extendable tool is used to identify the VAK III Seals
It is normally used in a 4.5 m configuration, with the driving motor located in the upper part.
In its short configuration, it can be used for identification in "Dry" conditions (see also fig.4 next page).
To make an identification it needs to be provided with a transducer:

Aerotech, 10 MHz, Focussed (about 2")

Immersion, medium damped transducer

Parts are: (1,1)=Lower extension shell; (1,1)=Connecting sleeve; (3a)= Sliding blades; (4a)=Triggering magnet (abandoned); (5a)=Sleeve; (6,0)=Transmission section lower sleeve; (6,1)=Transmission section tube; (6,2)=Transmission section upper sleeve; (6,3)=Guiding sleeve; (7,0)=External section lower sleeve; (7,1)=External section tube; (7,2)=External section upper sleeve; (8)=Motor box; (9)=Bearing plate; (10,0)= Upper transmission axle; (10,1)=Guiding extension for the

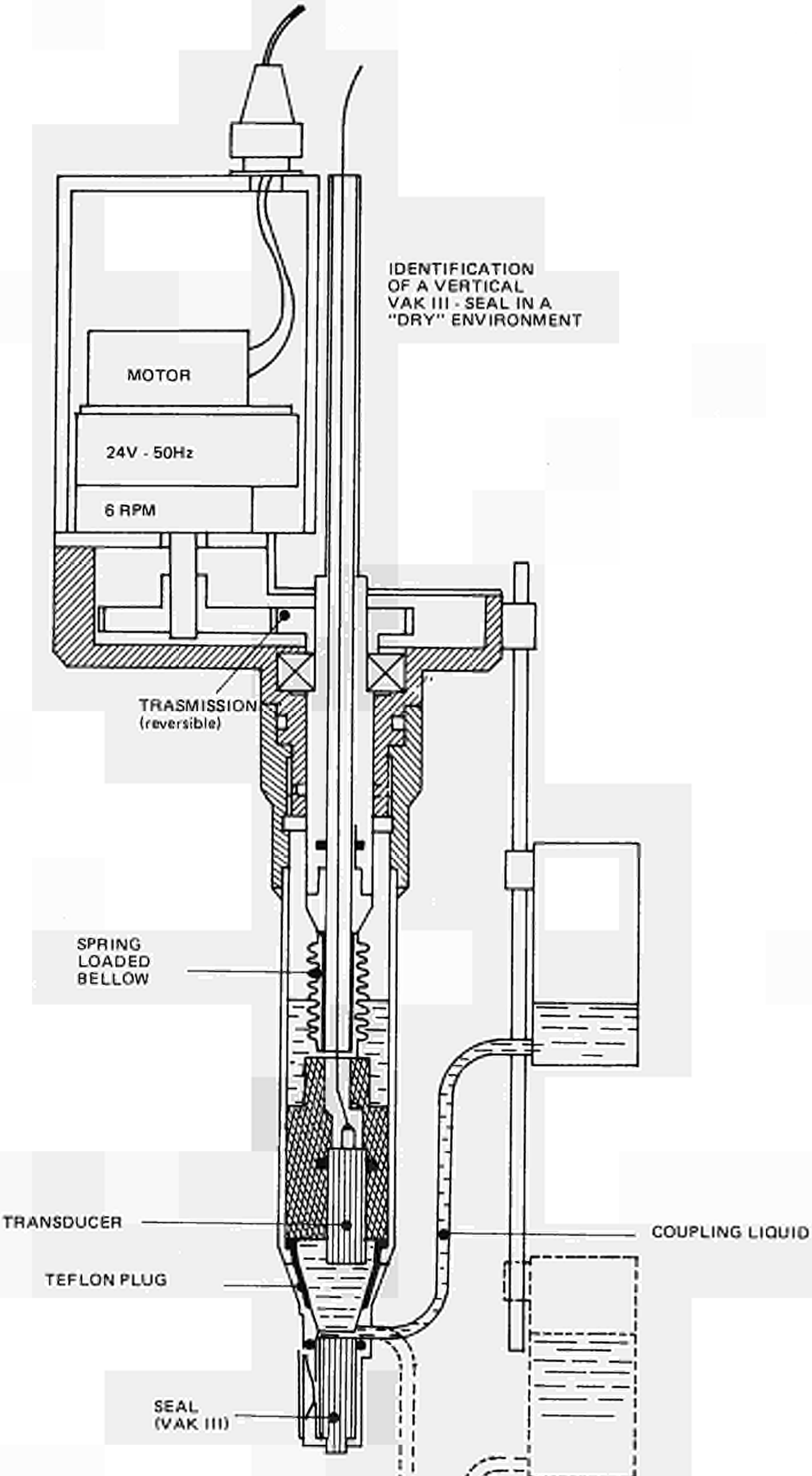


FIG. 4:

Identity Tool for
Dry Measurements.

wire; (11)=Motor plate; (12)=Secondary gear hub; (13)= Motor gear (Z=100); (14)=Secondary gear (Z=85); (15)= Sliding thrust washer; (16a)=Transmission bellows; (18)= Adjusting screws; (19)=Schnorr washers; (20)=(21)=(22)= (23)=O'rings; (24)=(25)=(26)=Screws; (27)=Motor gear hub; (28)=Screws; (29)=Locking screw; (30)=Ball bearing; (31)= Screws; (32)=Electric motor (presently, the motor is a Crouzet, reversible, 24v, AC 50 Hz 3 W motor which gives to the secondary axle a speed of about 5 rev/min); (33)= Transducer (not part of this tool);(34)=Seal under measurement (not part of this tool); (35)=Magnetic switch (abandoned); (36a)=Centering pins; (37)=Locking screw; (38)=Lid; (39)=Screw; (40)=Seal pressing key (modified in the last version the seal having no lateral groove); (41)=Eccentred hollowed transducer drum (while it rotates around the main axis, the transducer describes a circle of 3.5 mm radius); (43)=Third sliding blade; (44)=O'ring (all O'ring are now removed from the tool in order to ease the water passage).

Note v): The "dry" identity tool is made of the same parts (no extensions). It has a special water vessel which can be adjusted at different levels

Note w): For the October 1984 Campaign, a modified Identity Tool is being prepared, in which the motor would be kept near to the rotating lower extremity (as in the "dry" configuration) and immersed in water. Thus is would be possible to use - without long rotating transmissions - in any deepness of water and - in particular - directly on the F.A. located in the normal pool storage. The use of an immersed miniaturized CCTV is also contemplated.

4.2.2 The Integrity Tool

Refer to Annex II, Drawing 81-1194-OA- c and § 2.3.2

This tool has no mechanism. It fits to the seal in the same way as for the Identity Tool. It brings a transducer (same type as above), centrally at a distance of 15 mm from the seal upper edge. It has been adapted, too, to the last presentation of the VAK III Seal.

Parts are: (1d)=Transducer bearing shell; (3a)=Adjusting screws; (4)=Schnorr washers; (5)=Tube lower end; (5,1)= Tube; (5,2)=Tube upper end; (6)=Extension lower end; (6,1)= Extension; (6,2)=Extension upper end; (7)=Upper tube lower end; (7,1)=Upper tube; (7,2)=Upper tube upper end; (8)= Hook; (10)=Centering pins; (11)=Seal pressing key (see above part nb 40); (12)= Cover (not used at Kahl); (13)=(14)=(15)= O'rings not installed in the present version, in order to ease the water entering the tool; (16)=Transducer (not part of the tool); (17)=O'ring for the junction; (18)=Locking screw for the transducer; (19)=Bolt; (20)=Seal (not part of the tool).

5. INSTRUMENTS

It has been said in the previous 2.3.3 paragraph that the Instrumentation meets the requirement of five Operating Functions, which are recalled below:

- Breaking Function (vi)
- Identity Measurement Function in water (vii)
- Identity Measurement Function in air (viii)
- Integrity Measurement Function (ix)
- Signature Identification Function (x)

We will list the instruments which are used in correspondance with each function and give their main characteristics.

We will indicate whether the mentioned instrument is:

- Necessary for Demonstration purpose only (Dem.)
- Necessary for Practical Inspection (Ins.)
- Facultative but helpful (Fac.)

5.1 Instruments for breaking measurements (Fac.)

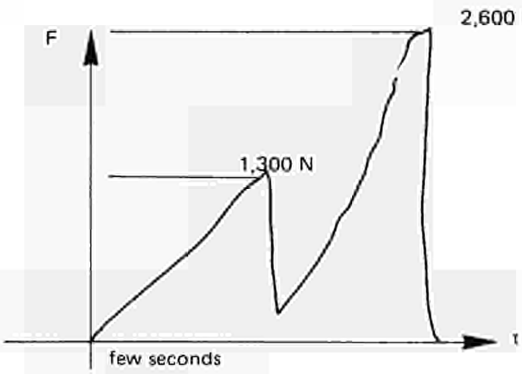
Breaking a Seal is a necessary function. Measuring the breaking forces of the DOBRIC is facultative.

The material used is (see fig.5):

- 3 strain gages installed on part nb 46 of the breaking tool

  They are connected in series in order to compensate any traction rod flexion.
- One Amplifier Tektronix (Measuring Bridge) (Dem.)
- One Analog Chart Recorder Hewlett-Packard (Force)(Dem.)

As the traction force is increased, a graph as the one below is obtained, indicating the 1rst breakage in the Seal and the 2nd breakage, on the tie-rod extension.



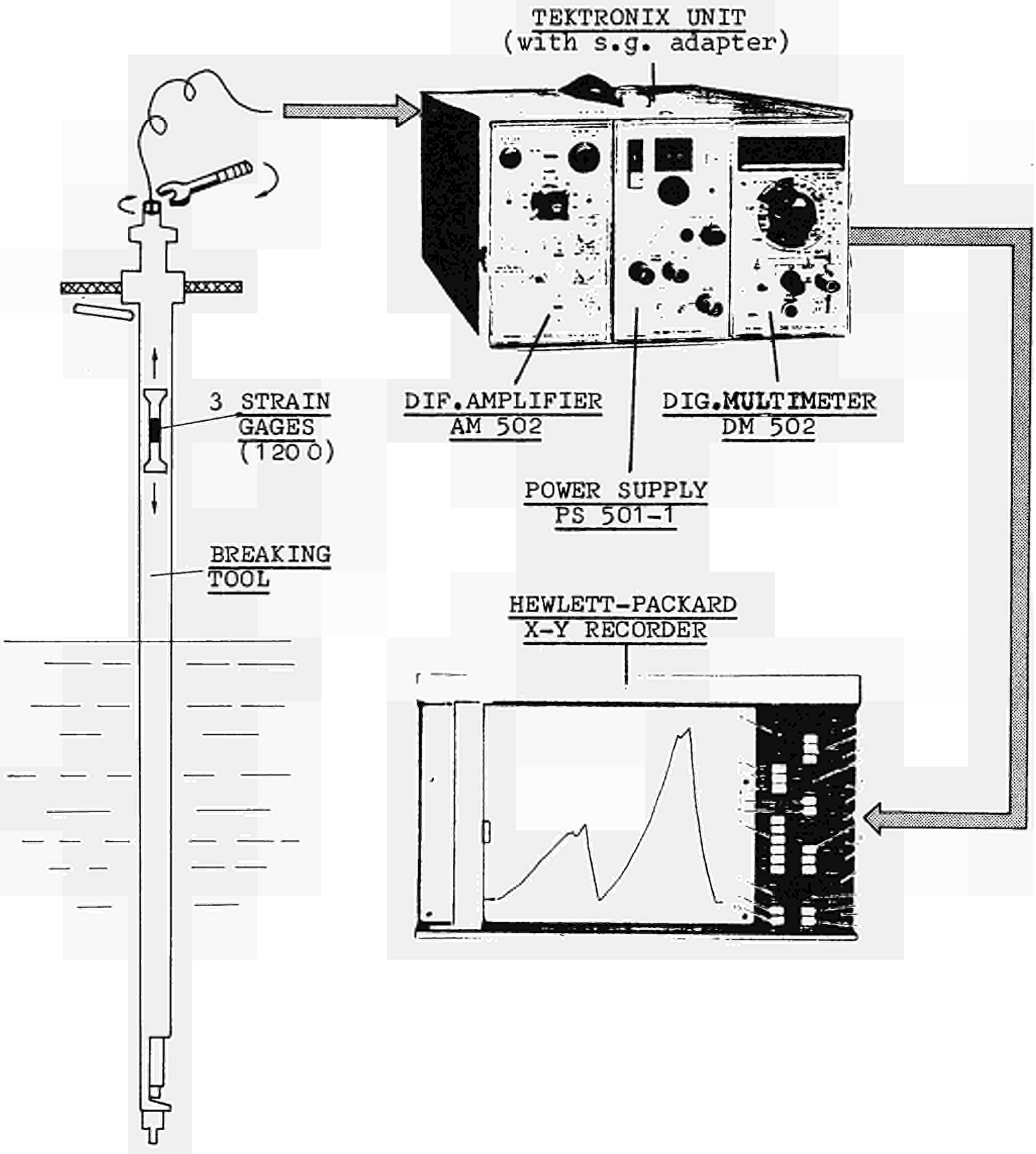


FIG. 5 Instruments for Breaking Measurements

5.2 Instruments for Identity Measurements (Dem.)(Ins.)

In the present VAK III Sealing System, the basic operation is to take the Seal Signature and to Store it.

We consider that the immediate simultaneous observation of the Seal Signature, as the Seal is scanned by the Identity Tool Motor , on a Chart Recorder (or may be, in the future, on a large screen CRT) is fundamental for the purpose of the Demonstration but also very helpful during a routine Inspection, even if not indispensable.

The SONIC Instrument is, in the present stage, a basic instrument for the Integrity checks. It provides a small CRT which facilitates the Setting of the apparatus prior to start an Identity Taking.

The Signature is not the curve seen on the CRT, but the one obtained, during the Seal is scanned, as an output of the Sonic Instrument, working in "Amplitude Gate" mode. This has been described in /3/ page 93.(*)

In October 1984, a new Compact Instrument should be presented by JRC Ispra as an attempt to group all the Measuring and Recording Items in a Single Transportable Box. It would offer one direct analog visualisation of the outcoming signature, but a delayed digital graph on a small incorporated printing machine. This instrument is called: VAK 45

The material used is: (see fig. 6):

Before October 1984:

- 1 Ultrasonic Instrument: SONIC FTS MARK I

  330 x 95 x 240 mm w = 5.4 kg (CRT Screen: 70 x 56 mm)
- 1 Analog Paper Recorder: HEWLETT-PACKARD 7015 B

  450 x 260 x 120 mm w = 7.2 kg (Paper Format: A-4)
- 1 Analog Cassette Recorder: PHILIPS MINILOG-4

  275 x 135 x 270 mm w = 13.5 kg (Normal 0.15"cassettes)

After October 1984:

- 1 Compact Instrument: JRC VAK 45 BOX

  470 x 290 x 360 mm w = 9 kg approx.

  Contains: The SONIC as above
  - A PC 1500 SHARP Computer and Peripherals
  - A MC 12 BMC Interface (Analog/digital converter)
  - A Power supply and Trigger for the Identity Tool

  It is used also for the Signature Identification (§ 5.3)

(*) Given in Annex IV

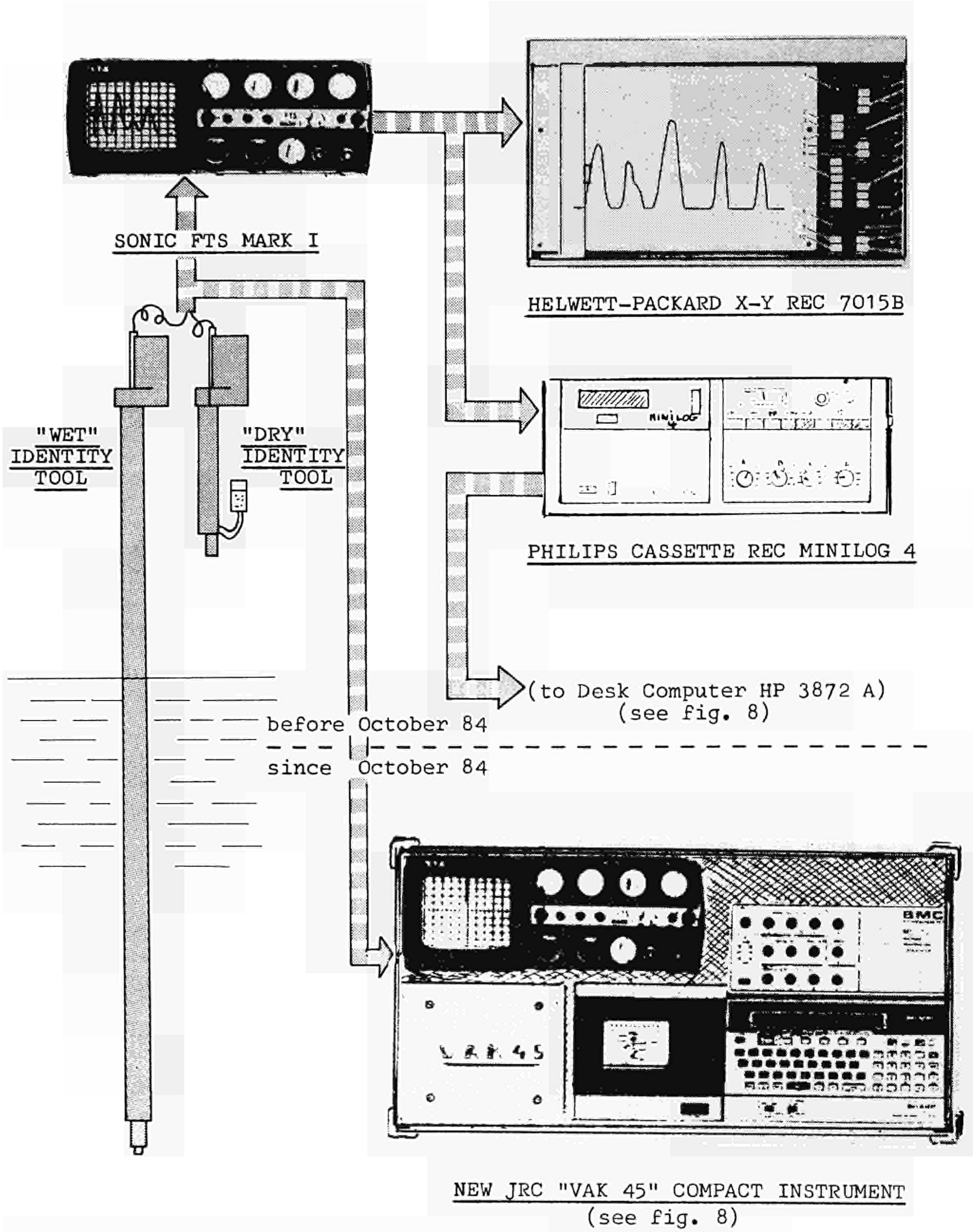
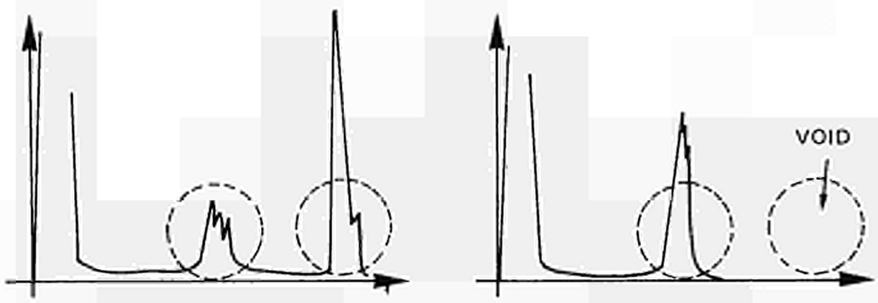


FIG. 6 : Instruments for the Identity Measurements

5.3 Instruments for the Integrity Check (Dem.)(Ins.)

The Integrity measurement requires, in connection with the Integrity Tool, the use of the same ultrasonic instrument as for the Identity taking (see $ 5.2 above).

Due to the kind of echogramm which is expected to appear on the SONIC CRT Screen as on the following picture (see also page 9 §2.3.3), a simple look at the window informs the Inspector on the Seal's Integrity Status



unbroken broken

If the Inspector wants to record the echogramm, he can take a picture of the CRT with a specially adaptable Polaroid camera. This was useful for demonstration purposes but is only facultative in the inspection context.

The material used is: (see fig. 7):

Before October 1984:

- 1 Ultrasonic Instrument: SONIC FTS MARK I (Ins.)

  (As for the Identity Measurement, but working in normal mode; it means with no record of the "Amplitude gate")

- 1 Polaroid Camera: LAND CU 5 3" (Dem.)

  w = 2 Kg

After October 1984:

- 1 Compact Instrument: JRC VAK 45 BOX

  (As for the Identity Measurement, using only the SONIC apparatus incorporated in the compact inst.)

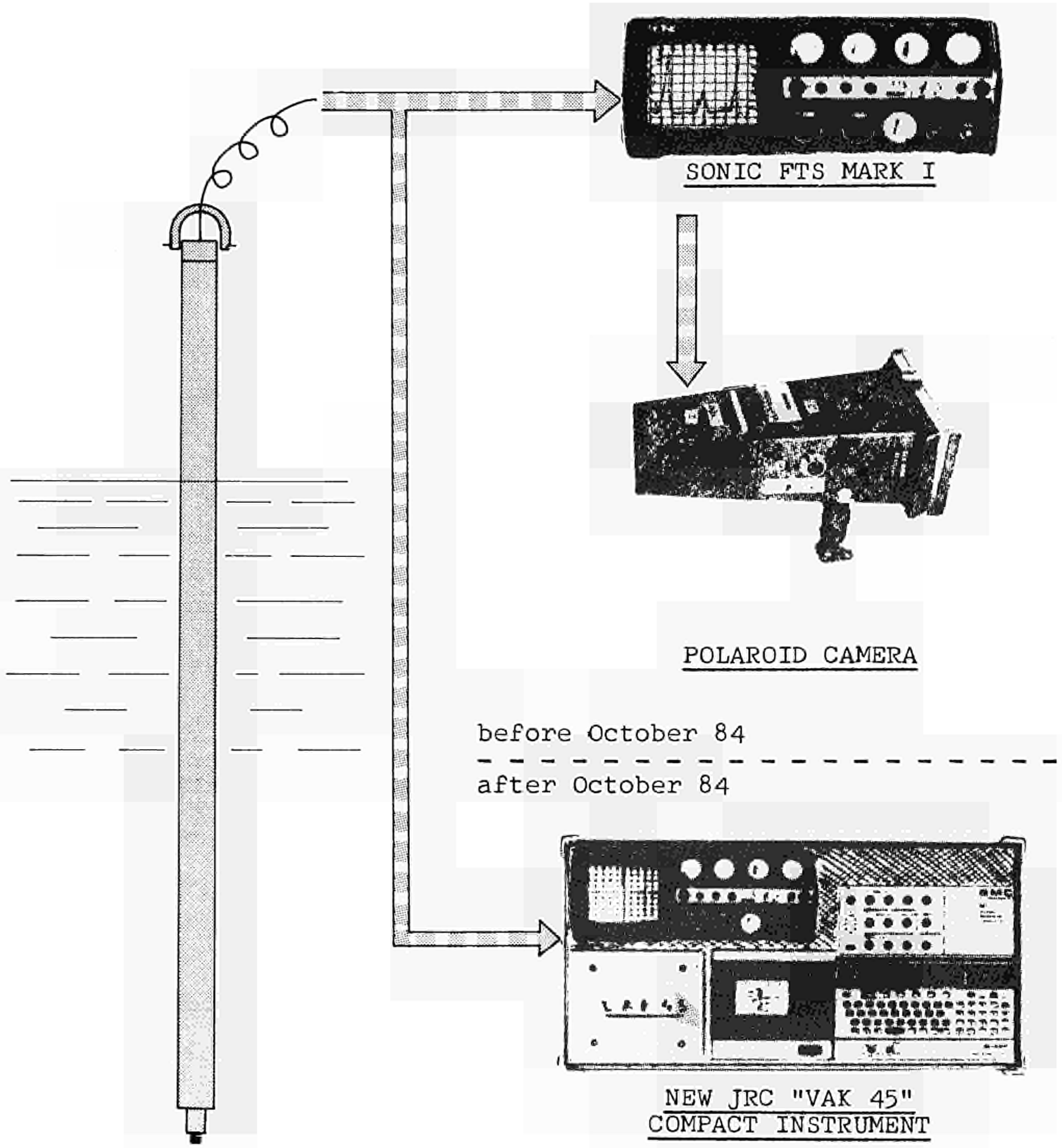


FIG. 7 : Instruments for the Integrity Check

5.4 Instruments for the Signature Identification

Once a signature has been recorded, during the Identity Measurement, it must be compared to another one, recorded previously, in similar conditions (§ 5.2 and fig. 6).

As explained in § 2.3.3, page 9 and 10, the VAK III Sealing System can perform such comparisons with three different means.

a. Graphical comparison: (Dem.)(Fac.)

The material used is:

- 1 Analog Paper Recorder: HEWLETT-PACKARD 7015 B

as described in § 5.2

Two diagrams can be traced on a same A/4 sheet, or on separate sheets, so that they can be superimposed and compared by transparency.

b. Correlation calculations on a Desktop Computer: (Dem.)(Ins.)

This has been used for the indentification processing until October 1984, for the VAK III MEI Seals and for some VAK III MEI b Seals. It is used routinely in laboratory.
The material is normally used in a room near the reactor, and transported at the reactor plant for the purpose.
It is described in fig. 8.

- 1 Analog Cassette Recorder: PHILIPS MINILOG-4

from which the data stored on a conventional cassette are transferred to the Computer System (see also page 24)

- 1 Desktop Computer System: comprises:
  - 1 Desktop Computer Unit: HEWLETT-PACKARD 9825 A
    383 x 129 x 495 mm w = 11.8 kg (23 Kbytes RWM)
  - 1 System Voltmeter: HEWLETT-PACKARD 3437 A
    213 x 89 x 527 mm w = 5.5 kg
  - 1 Digital Plotter: HEWLETT-PACKARD 9872 A
    500 x 500 x 155 mm w = 15 kg (Fac.)

c. Correlation calculations on the Compact Instrument: (Ins.)

This is being used after October 1984. It is a prototype of a compacted instrumentation. It is transportable and is used for all the performance of the last four Operating Functions (vii, viii, ix and x ,page 3). Useable on site.

The material used is: (see fig. 8):

- 1 Compact instrument: JRC VAK 45 BOX
  (see: § 5.2)
  - 1 Minicomputer: SHARP PC 1500
    195 x 25 x 86 mm w = 0.375 kg (ROM 16 Kbyte) (RAM 3.5 Kbyte) (+ 16 Kbyte ROM/RAM)
  - 1 Tape recorder: SHARP CE 152
    116 x 187 x 32 mm w = 0.6 kg (normal 60' cassettes)

  a standard 60' cassette can normally save 50 Seal Signatures

  with a spacial TRAM interface, it saves 1000 Seal Signatures
  - 1 Four colours printer: SHARP CE 150
    300 x 50 x 115 mm w = 0.9 kg

  prints R values and other indicators; plots the two Signature Curves in comparison; plots the R (s) curve; prints, on request , one or two Decision Thresholds, in order to discriminate between the two situations: "Same Seal", or "Different Seals".

The data are acquired from the SONIC Instrument through a special interface:

  - 1 Five channels Multimeter: BMC MC 12 SYSTEM

  specially studied to adapt on the PC 1500 Unit.
  179 x 79 x 49 mm w = 0.5 kg appr.

note x): Either the H-P Computer or the SHARP Minicomputer calculate, for two compared signatures, the Bravais-Pearson (correlation) Coefficient, the signals being digitized (Xi,Yj)

$$R(s) = \Sigma(X_i-\bar{X})(Y_{i+s}-\bar{Y}) \;/\; (\Sigma(X_i-\bar{X})^2\Sigma(Y_{i+s}-\bar{Y})^2)^{1/2}$$

a plot of $R_{(s)}$, where s = j-i is normally drawn while s can be any chosen value. When i = j, s = 0 and the computer indicates only one R value (see /4/)

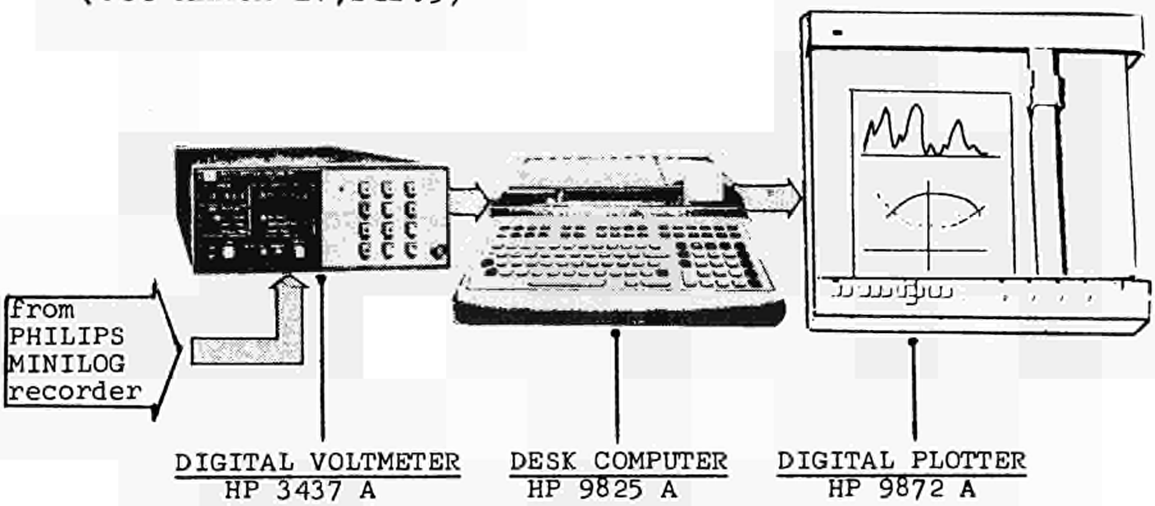
When R is near 1, the correlation between the two signatures is high and the statement is: "Same Seal". When R is near 0, or negative, the correlation is low and the statement: "Different Seals" is correct.

d. Compact Instrument since 1985: (Ins.)

Since the beginning of 1985, another compact instrument has been put into operation. It is lighter than the VAK 45. It does not incorporate the SONIC instrument but has room to host a dedicated electronic instrument when the use of this sealing system will be decided. Presently, it is connected to a conventional SONIC Instrument. The computer is same as for the VAK 45.

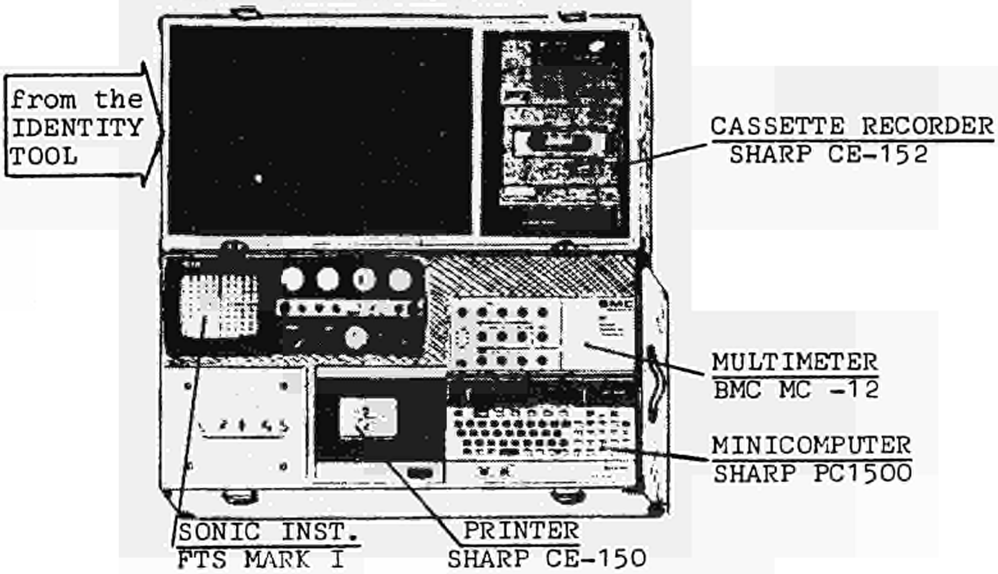
- 1 Compact instrument: JRC VAK 18 BOX

(See Annex IV,ref.5)



before October 1984

after October 1984



COMPACT INSTRUMENT
JRC VAK 45

FIG. 8 : Instruments for the Signature Identification

6. PROCEDURES

Between the manufacture stage and the use in actual conditions, the VAK III Seal undergoes the following procedures. This is a general indication and has to be considered with a certain flexibility. We use to call "Phases"the different steps in the life of a seal.

6.1 Phase 0 (Laboratory)

After its fabrication, the seal is checked in Identity and Integrity. The operations are achieved in Laboratory.

The Integrity check provides:

- 1 Photogram with a typical shape (Polaroid)

The Identity measurement is done two times (or more). The Identity measurement is performed in water with a short tool (Phase 0), then with another transducer - or tool - which corresponds to the Phase 0', and so and...
The operators are provided with at least one diagram per measurement.
Each measurement is also normally stored on a cassette.

- 1 Diagram (signature) for Phase 0
- 1 Diagram (") for Phase 0'
- 1 Diagram (") for Phase 0"

If a batch of n seals is prepared, the computer is used to calculate:

- n "autocorrelations" (Phase 0 compared with Phase 0')
- n(n-1)/2 "crosscorrelations"(Phase 0 compared with Phase 0)
  or (Phase 0 compared with Phase 0')
  or (Phase 0' compared with Phase 0')

For that batch of - say - 24 Seals, 24 "autocorrelations" are made and 276 "crosscorrelations" should be calculated, which is a large number. Sometimes, a smaller amount of cross-correlations is calculated and an "indicative histogram"can be drawn and two characteristic values - or thresholds - can be empirically determined indicating the higher coefficient of cross correlation and the lower coefficient of auto correlation : C_{Mx} and A_{mn} .

These values: C_{Mx} and A_{mn} can be introduced as parameters of that batch as decision thresholds.

Should a correlation value between two unknown signatures fall inside that range, other estimators can be used (ref/4/)

6.2 Phase 1 (Reactor)

Once a seal has been clamped onto a F.A., it must be checked again.
The integrity and identity tools are now used in the reactor pool.

The integrity check in done as for Phase 0 and :

- 1 Photogram with an Integrity diagram is taken (Polaroid)

and visually compared with the Phase 0 one, or normally checked with a look at the peaks.

Note y): When, for demonstration purposes, the seals are clamped by the same person who brings the seals, that check is not necessary.

The identity measurements are done with the Identity Tool, in the pool (after October 1984 also in the dry storage), in conditions similar to the one of Phase 0

Similarly to phase 0, two - or more - acquisitions can be done and compared between themselves. A Diagram can be obtained on a chart recorder, but it is not necessary.
Each measurement is stored on a cassette (analog cassette until October 1984)

- 1 record for Phase 1 (for instance in the dry storage)
- 1 record for Phase 1' (for " on the pool stripping machine)
- 1 record for Phase 1" (repetition on the same day)

Again, for n seals,n 1/1' or n 1/1' or n 1'/1" "autocorrelations"can be calculated. The experience, in the past, has shown that one of the three possibilities is sufficient.

Similarly to Phase 0, different possible kinds of "cross-correlations" can be calculated, but the most important requirement is to compare Phase 1 with Phase 0 , and the n(n-1)/2 "cross" 0/1 (or 0'/1, or 0'/1') must be calculated.

6.3 Phase 2 (Reactor)

After six months or one year, the check of the seals is being done, and each of them will be measured again and the operator (or inspector) would get:

- 1 Integrity photogram
- 1 Identity record for Phase 2 (Phase 2' is not necessary except in case of doubt about a seal's identity)
- n "autocorrelations" (Phase 1 / Phase 2)
- n(n-1)/2 "crosscorrelations" (Ph 1 / Ph 2)

must be calculated too.

6.4 Adjustment Procedures

On the SONIC instrument, past and present experiences have led to the definition of routine procedures.

6.4.1 Identity Adjustment:

For VAK III MEI b Seals

- Wire: Length: 8.40 m; Diameter: 2.5 mm; Resistance 50 Ωhm
- Rear Panel: Rep. Rate: 3KHz ; Filter: Off ; Video: Normal
- AC Supply: Supply cord on 220V-50-60 Hz
- CC Lemo connector pushed in.
- Front Panel:

- Freq.: 10 MHz
- Normal Synchronization: Normal
- Position Width, Dec Slope : To be adjusted before and after operating
- First Echo: End after the last echo
- Damping: HS
- Power ON at least 10' before starting
- Delay: 4.50
- Range: 40
- Mat/Cal: 1-60
- Gain: Adjust 3 V Sonic Output

6.4.2 Integrity Adjustment:

For VAK III MEI b Seals

- Wire: As for the Identity
- Calibrating Block: Stainless Steel Cylinder, Diameter: 13 mm, Length: 23 mm, must give on the CRT: 1rst peak on 1 div. and 2nd on 8 on scale 3
- Rear Panel: Rep. Rate: 3 kHz; Filter: Med; Video: Normal

- Front Panel:

- Reject: Out
- Gain: to be adjusted later on
- Norm. Sync.: Off
- Position Width, Dec Slope : Out
- Damping: Out
- Power ON at least 10' before starting
- Delay: 3.20
- Range: 20
- Mat/Cal: 1-10
- Normal-Thru-Trans: Normal
- Adjust in order to have the 2nd peak with a magnitude of 80% of the vertical range on the CRT.

6.5 Recording Procedures

6.5.1 Graph Recordings

- Normal use of an instrument such as H-P X-Y REC 7015B (fig.6)
- Output: a graph on A - 4 sheet (fig. 9)

6.5.2 Plotters

- Normal use of the H-P 9872 A Plotter as a peripheral of the Desktop Computer H-P 9825 A (fig.8)
- Output: a plot on A-4 sheet (digital plot) as in fig.10

- The plotting is controlled by the minicomputer programme, in the case of the new VAK 45 Compact Instrument The printer (fig.8 below) delivers a correlation graph as in fig.11
- Ouput: a multicoloured 240 mm length strip of paper, giving:
  - the two signatures in comparison
  - the $R_{(s)}$ and $DD_{(s)}$ functions (corr. and diff. estim.)
  - the corresponding values and the ones of $R1_{(s)}$
  - the thresholds A_{mn} (upper thr.) and C_{Mx} (lower thr.)
  - the statement "Same Seal" or "Different Seals" in green or in red coloured printing
  - the data for date, place, instrument, Seals n° etc...

6.5.3 Tape Recordings

- Normal use of the MINILOG 4 Cassette Recorder (fig. 6)
- Output: a cassette storing analog signatures, ready to load the DIGITAL HP 3437 A Voltmeter (fig.8)
- In the VAK 45 Compact Instrument the use of the Digital Cassette Recorder SHARP CE-152 can be either independant or controlled by the Correlation programme. (fig.8)

6.6 Correlation Procedures

A pre-determined programme calls two signatures which are stored on a digital special cassette, in the Desktop H-P Computer housing, when the old system is used.

A similar procedure is used in the VAK 45 Compact Instrument, apart that only one tape recorder is used for all purposes.

But the instructions for the performance of the correlation appear on the Minicomputer window.

An example of the instructions or questions appearing on the Minicomputer Window is given below.

They represent the logical operations one has to perform while comparing two signatures.

They are flexible and could be optimized according to the specific wishes of the potential user.

- Number of Points ? : Choose the number of values you want to put in one signature curve (i and j from 0 to n) Higher you choose n, longer the correlation duration.
- Trigger level ? : Choose the level of the first peak of the random signal you want to start the digitization with.
- Load from a cassette : Prepare the cassette you want to examine (if yes)
- Seal Number ? : Call on that cassette the data of that particular seal
- Tape Position ready ? : Starts the data transfer in the Computer memory (loading)
- Load from another cassette: Prepare the second seal cassette if it is not on the same as the first one
- Seal Number ? : Call the data of the second seal
- Two signatures ready ? Asks for the right loading of the two signatures under comparison
- Choose a smoothing value: You may decide to introduce a simple smoothing process of m points, in case of high noise. But it is normally not used (m = 0)
- Do you want a plotting ?: Asks if you perform a single check or a complete correlation process
- Do you want a shift ?: Asks wheather you want the R(s) function be calculated or you consider the general precision of the measurements sufficient to find at the 1rst correlation calculation the correct representation of the actual correlation between the two signals. If yes choose the shift interval (number of points: s) and if desired, give a step when you want a discontinuous shift.
- Start the correlation:

With n = 100 points and a 5 points shift, the complete process has a duration of few minutes according to the parameters required by the operator.
If no shift is called for, the process has a duration of 1 to 2 minutes.
The advantage of the incorporated computer is to introduce a great flexibility in the procedures.
Following, is a flow-chart of the Program presently in use.

FLOW CHART

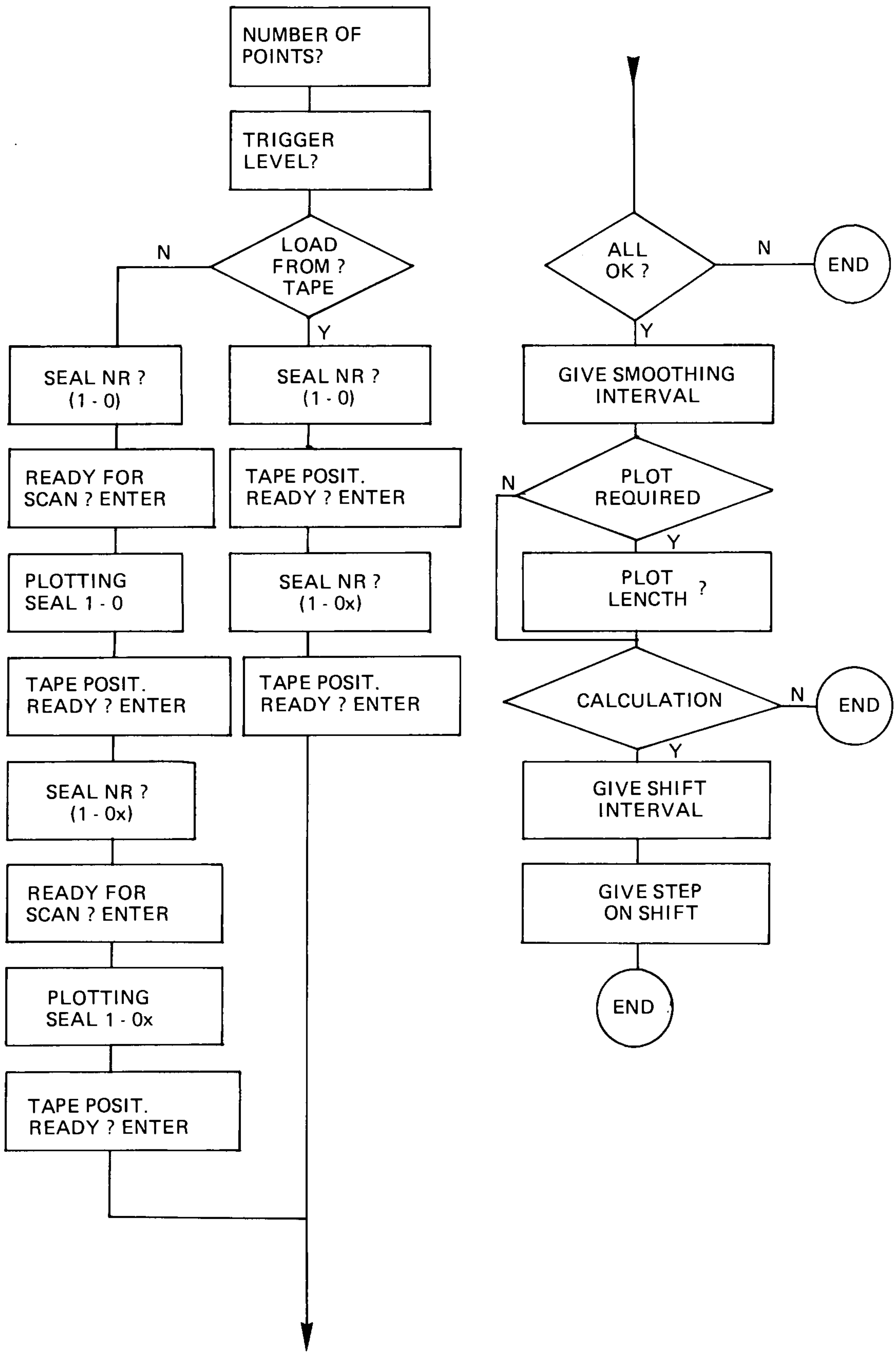
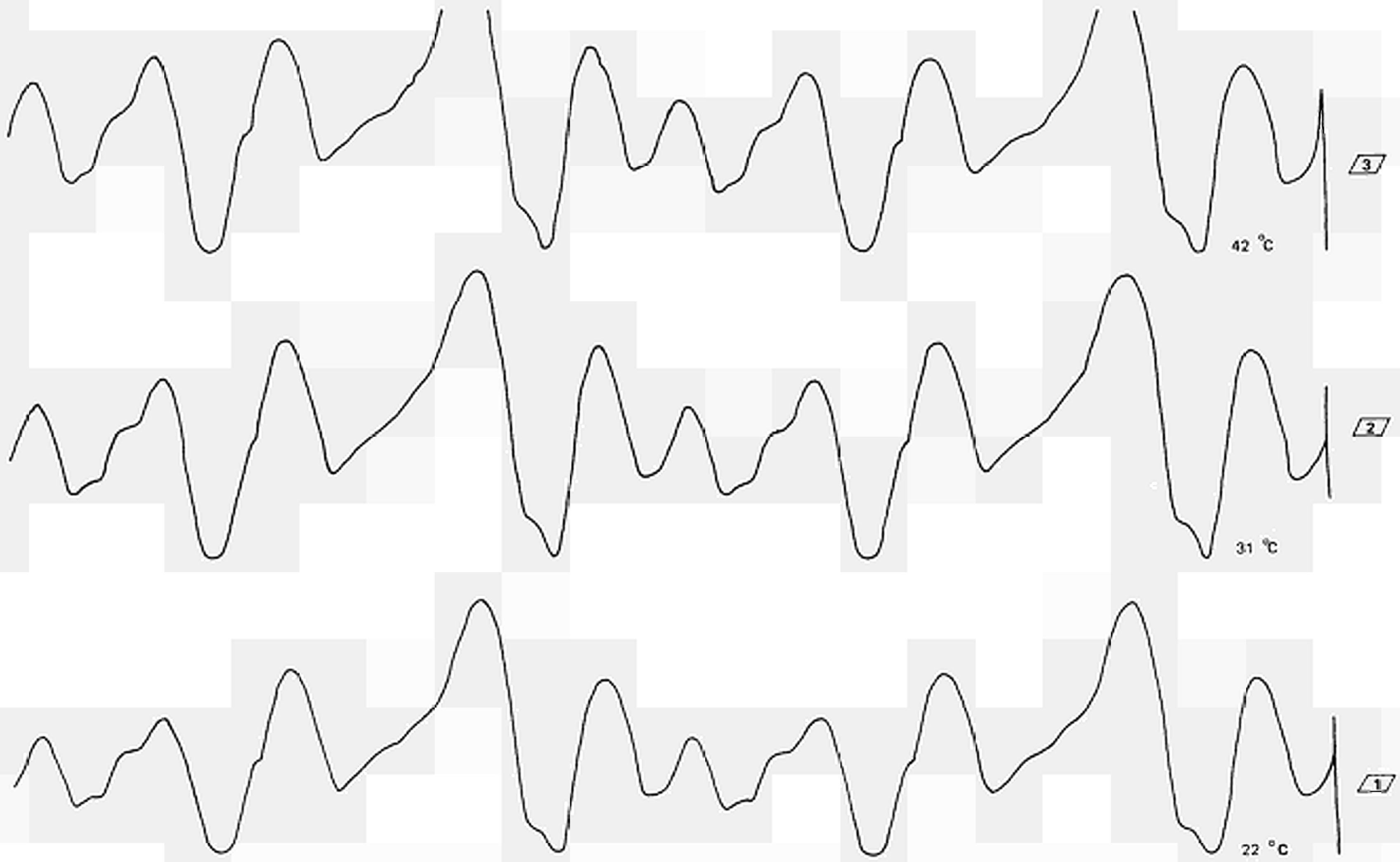

NUMBER OF POINTS?
TRIGGER LEVEL?
LOAD FROM ? TAPE
N
Y
SEAL NR ? (1 - 0)
READY FOR SCAN ? ENTER
PLOTTING SEAL 1 - 0
TAPE POSIT. READY ? ENTER
SEAL NR ? (1 - 0x)
READY FOR SCAN ? ENTER
PLOTTING SEAL 1 - 0x
TAPE POSIT. READY ? ENTER
SEAL NR ? (1 - 0)
TAPE POSIT. READY ? ENTER
SEAL NR ? (1 - 0x)
TAPE POSIT. READY ? ENTER
ALL OK ?
N
END
Y
GIVE SMOOTHING INTERVAL
PLOT REQUIRED
N
Y
PLOT LENCTH ?
CALCULATION
N
END
Y
GIVE SHIFT INTERVAL
GIVE STEP ON SHIFT
END

FIG. 9: Examples of Analog Singatures



VAK III-MEI SEALS IDENTITY GRAPHS 1 2 3	/1/ [illegible] Date: [illegible] Place: [illegible] Phase: AER n°: [illegible] T°: [illegible] Operator: [illegible] Cassette data:	/2/ [illegible] Date: [illegible] Place: [illegible] Phase: AER n°: [illegible] T°: 31°c Operator: [illegible] Cassette data:	/3/ [illegible] Date: [illegible] Place: [illegible] Phase: AER n°: [illegible] T°: [illegible] Operator: [illegible] Cassette data:

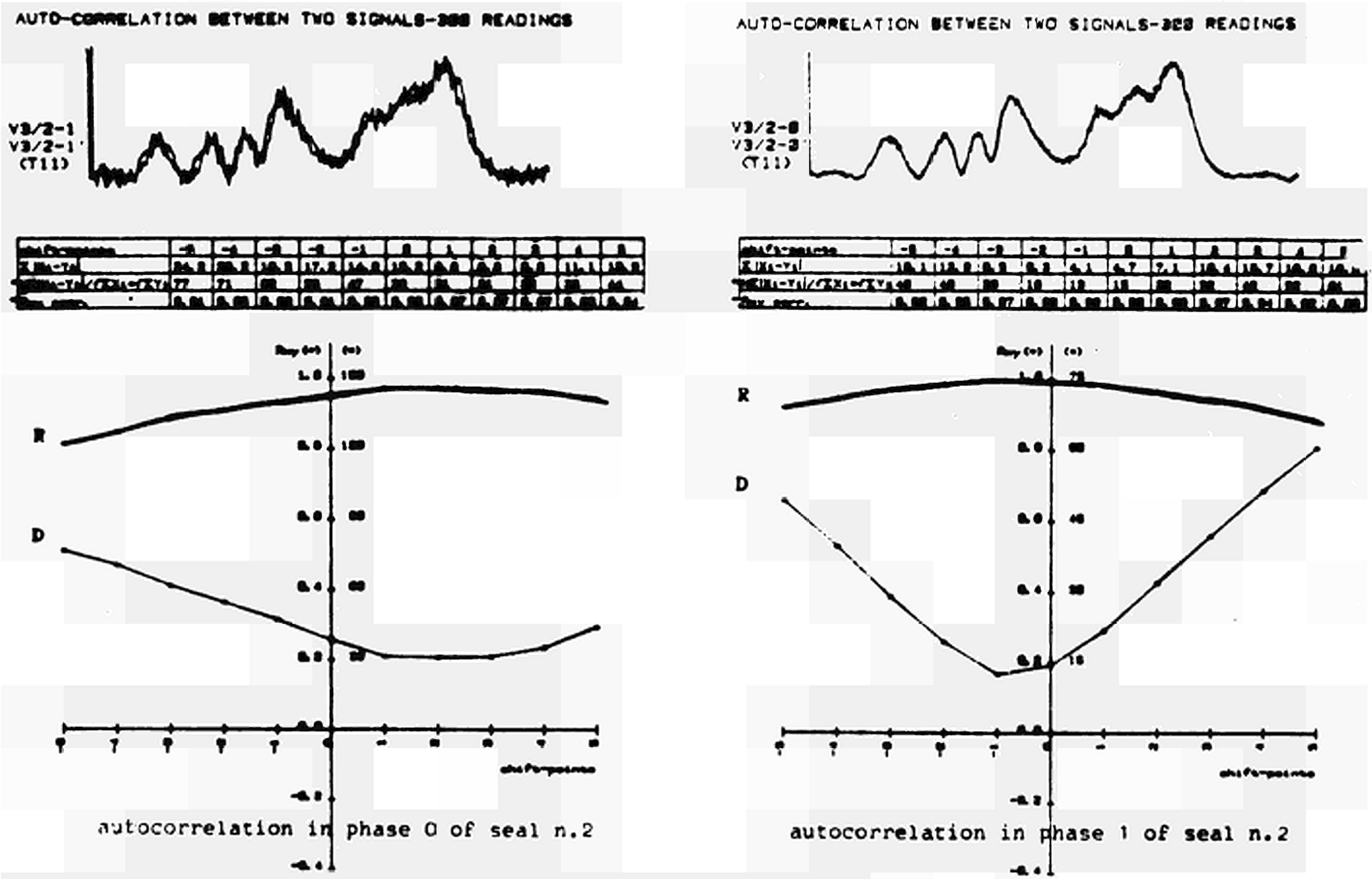
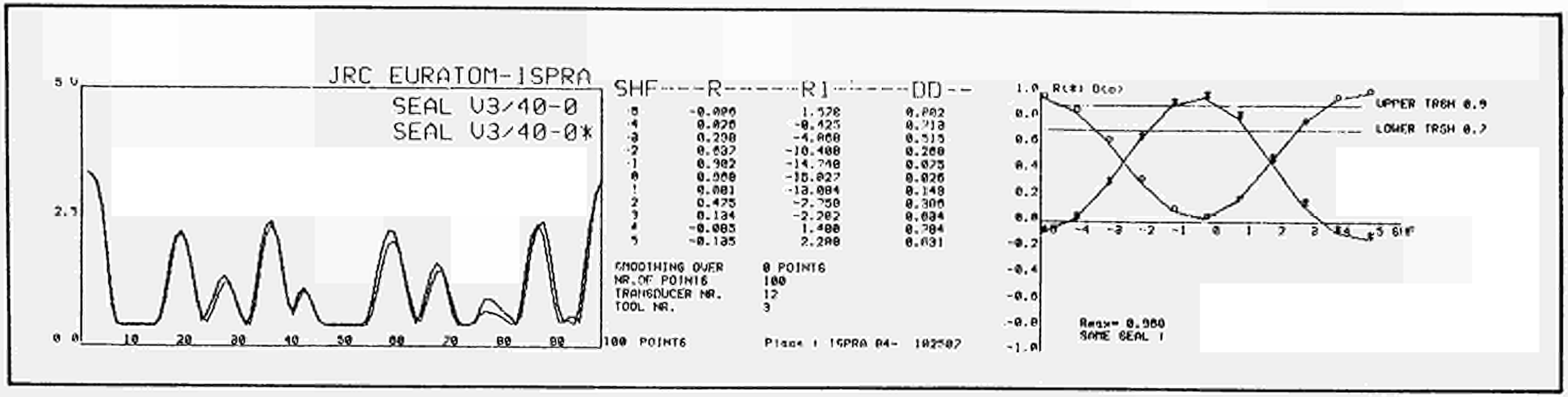
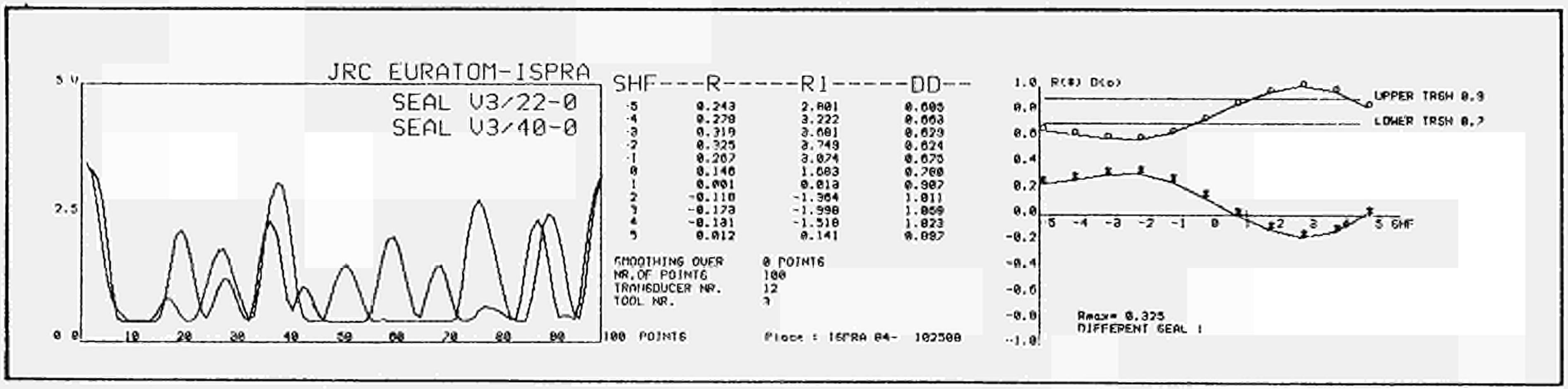


FIG. 10: Examples of graphs as they come from the digital plotter HP 9872 A (half-scale)



Correlation Graph obtained in case of the reidentification of <u>a same seal</u>



Correlation Graph obtained in case of the comparison of two <u>different seals</u>

<u>FIG. 11:</u> Correlation Strips a delivered by the new <u>JRC Compact Instrument VAK 45</u>

7. COSTS

As said before, the material used in this work is essentially designed for demonstration and/or feasibility studies.
Part of it has been developped and built in the JRC Workshops and affiliate. All the tools, for instance, were built in unique, or double exemplaries. Such prototypes have a cost which is certainly higher than in case of series production.
The seals, also, have been manufactured in limited batches.
The instruments from the market have been purchased with normal prices and are easier to estimate. Nevertheless, in the future, considerable simplification and cost reduction could be obtained while an Assessment Study would be achieved , indicating the points on which the potential users (IAEA, DCS) would have requirements

Costs are known or estimated on the basis of very small, unoptimized series.

7.1 Tools

	US$		Drawing
• Positioning Tool:	270	(est)	IX 71 918 OC
• Breaking Tool:	2,500	(est)	IX 72 929 OB
• Identity Tool (wet):	1,400	(est)	83 12 45 OA
• Identity Tool (dry):	1,200	(est)	
• Integrity Tool:	600	(est)	81 11 94 OA

7.2 Seals and bushings

• VAK III MEI b Seal:	190	(kno)	84 12 63 OA
• Special Bushing:	15	(est)	80 11 74 06
• Extended Tie-Rod End:	?	(built by Exxon)	

7.3 Instruments

• SONIC Mark I:	4,500	(kno)	
• POLAROID Camera:	650	(est)	
• AEROTECH Transducer:	250	(kno)	
• Thermometer (Facultative):	150	(est)	
• Trigger Black Box:	150	(est)	
• MINILOG Tape Recorder:	3,000	(est)	(abandoned Oct 84)
• H-P Analog x-y recorder:	5,000	(est)	(only for demonst.)

7.4 Computers and peripherals

- H-P Desk Computer 9825 A: 12,000 (est) (no more built)
- H-P System Voltmeter 3437 A: 5,000 (est) "
- H-P Digital Plotter 9872 A: 7,000 (est) (only for dem.)

before October 1984 -
after October 1984

The compact instrument is estimated:

- JRC VAK 45 BOX 6,500 total

including the SONIC (see above) and:

- SHARP Minicomputer: 450 (kno)
- SHARP Printer CE 150: 225 (kno)
- SHARP Tape Recorder CE 152: 45 (kno)
- BMC Interface MC 12: 850 (kno)
- Trigger Black Box: 190 (est)

Note z): The instruments used for the breaking demonstration (see pages 21 and 22) are expensive and not suitable for possible routine extraction operations. They can easily be replaced by less sophisticated measuring devices we had not at disposal while performing feasibility studies. The TEKTRONIX amplifier is estimated about 5,000 $ and could be substituted by an item 10 times less expensive, which it is possible to incorporate into the VAK 45 Box in the future.

8. CONCLUSIONS

A general description of the experimental VAK III Sealing System has been given with the particular intention to underline that a good level of feasibility has been reached.

We have shown that this system meets the requirements of three basic functions in particular through the very concept of the VAK III Seal which fulfills correctly the Locking, Identification and Integrity Functions.

Description and drawings are provided to explain how the Seal, as a mechanical structure, prevents the disassembling of the upper tie-plate of a Fuel Assembly on which top it has been clamped; and how, as an ultrasonically measurable item, it can indicate its Integrity Status and, consequently, the Integrity Status of the Fuel Assembly it protects.

The VAK III Sealing System meets other seven Operating Functions which we consider as essential in a Safeguards concept. These operating functions are fulfilled by the Handling Tools which are used, together with the Instrumentation to perform the Integrity Check, the Identity Measurement in dry or wet conditions, the Breaking or the Installation of the Seals.

As far as possible, we have indicated the techniques employed untill October 1984 separately from the new techniques prepared for the October 1984 Campaign in Kahl.

We consider that the main points of progress are:

- The Strong Random Internal Defects (STRID) incorporated in the seals, allowing the obtention of a good signature stability.

- The Integrity Check on the Seal Status (broken or not) obtained through a decisive mechanical improvement: the Double Breakage Integrity Check (DOBRIC) and with a better ultrasonic evidence of that status.

- The provision of new function tools, allowing the performance of Identity Measurements in dry conditions (which means also at the manufacturer plant) or in deeper water (wet storage).

- The study and development of a new JRC VAK 45 Compact Instrument Box, in which all the measuring functions can be grouped and incorporating an autonomous Minicomputer offering to the Inspection the possibility of performing, on the spot, Correlation and Decision processes

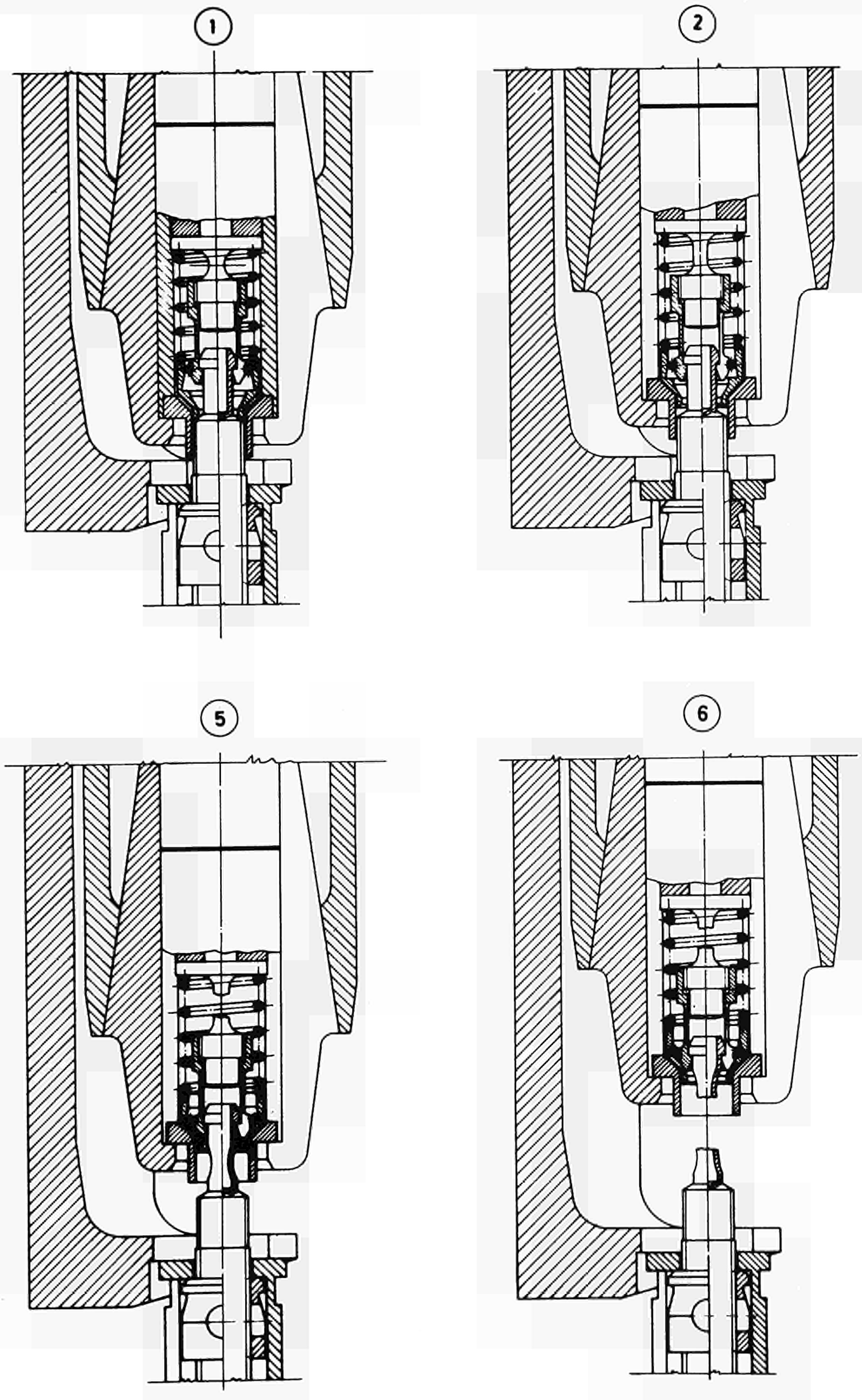
The general benefit of such a feasibility study should be to convince the potential users that such a Safeguards Sealing System can be studied for slightly - or largely - different other applications, provided that the Basic and Operating Functions required to the system be clearly defined, possibly after a common agreement would be stated.

VAK III SEALS and SEALING SYSTEM

ANNEX I

Contents: Drawings

84 12 63 0C
84 12 63 0A
84 12 63 0B M
83 12 50 12
80 11 74 06



N	DENOMINAZIONE	QUANTITA	MATERIALE	NORME E OSSERVAZIONI

PROGETTO: VAK III MEI - B

TITOLO: SEQUENZA DELLE FASI DI ROTTURA DEL SIGILLO

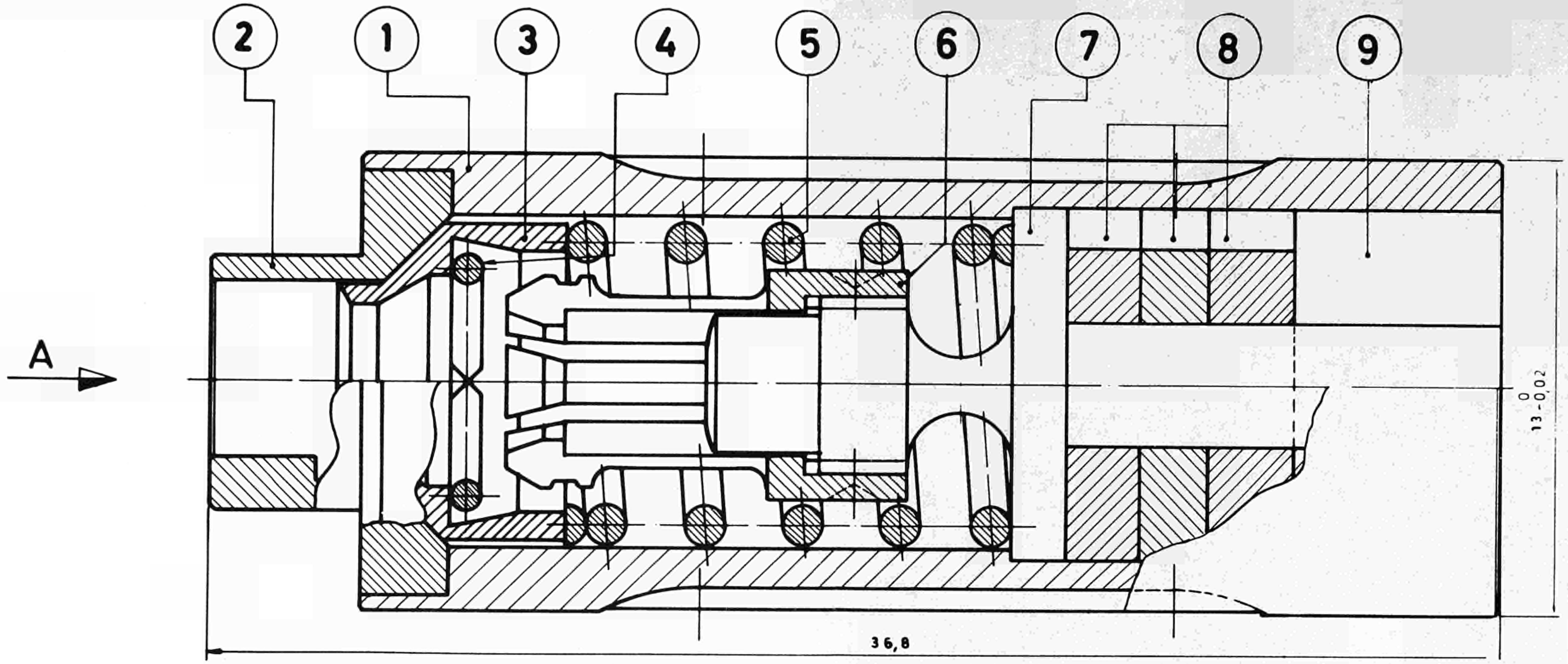
COMMISSIONE DELLE COMUNITA' EUROPEE
CENTRO - COMUNE DI RICERCA
STABILIMENTO DI ISPRA

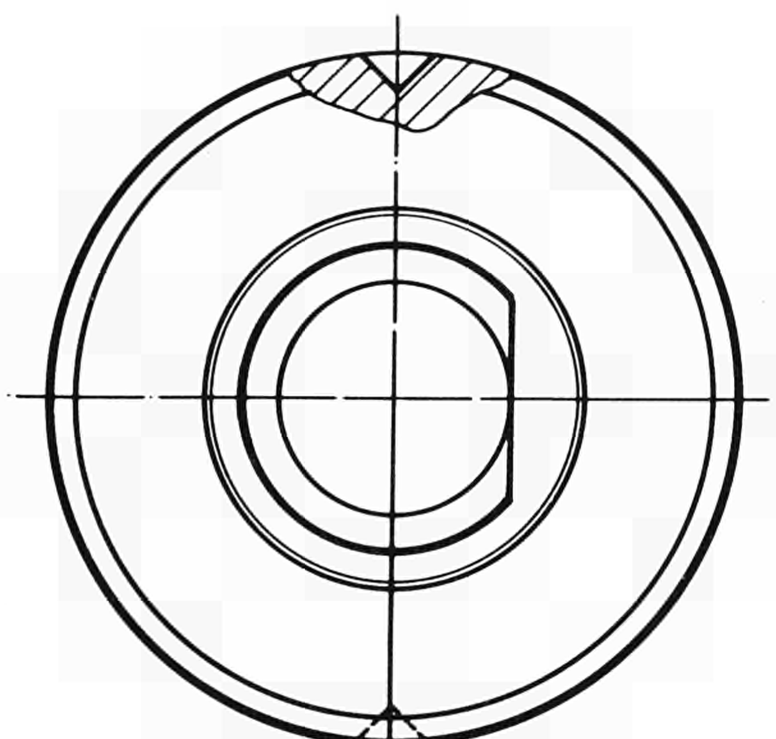
REPARTO: MATERIALI N D T LABORATORIES

SCALA 5:1

DATA 30-10-84

84-1263-0C





VISTA LATO A

N.	DENOMINAZIONE	QUANTITA'	MATERIALE	NORME E OSSERVAZIONI
9	TAPPO	1	AISI 304 L	
8	RONDELLA		AISI 304 L	
7	CODOLO	1	AISI 304 L	
6	PINZA	1	INCONEL X 750	2 ORE A 650° C RAFFR. IN ARIA
5	MOLLA	1	ACC. INOX PER MOLLE	
4	ANELLO	1	INCONEL X750	2 ORE A 650° C RAFFR. IN ARIA
3	BOCCOLA DI SPINTA	1	AISI 304 L	
2	PARTE INF. SIGILLO	1	AISI 304 L	
1	CORPO SIGILLO	1	AISI 304 L	

IND.	MODIFICAZIONE	DATA	FIRMA

PROGETTO: **VAK III MEI - B**

TITOLO: **ASSIEME SIGILLO**

FINITURA — RUGOSITA' = √ oppure ~ ∇ ∇∇ ∇∇∇

TOLLERANZE GENERALI: 0,1 — oppure 0,01 / 0,001

FUNZIONAMENTO

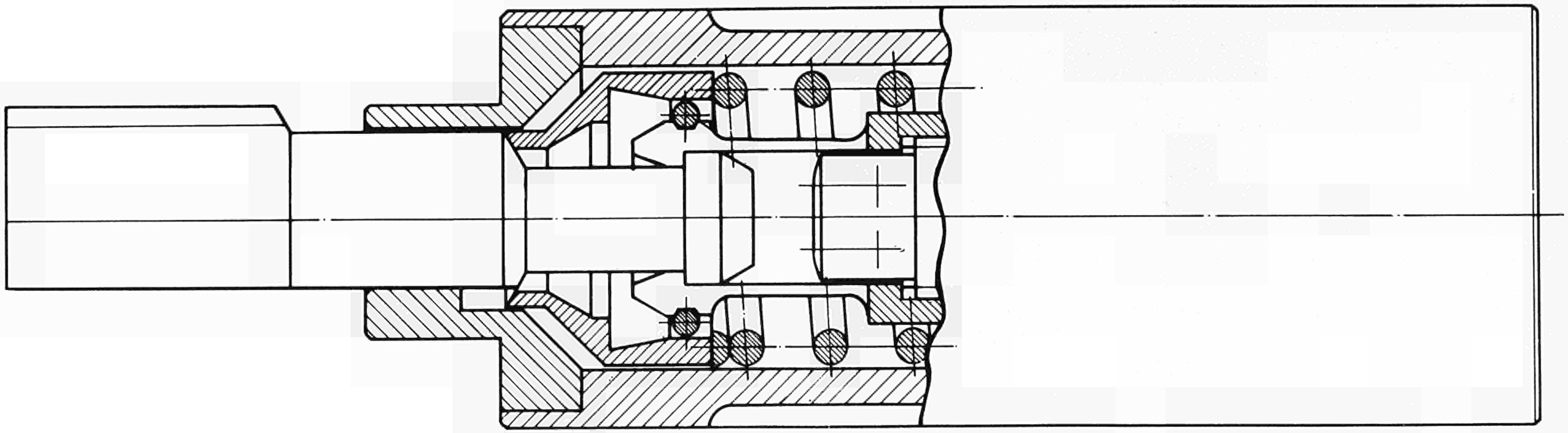
COMMISSIONE DELLE COMUNITA' EUROPEE
CENTRO COMUNE DI RICERCA
STABILIMENTO DI ISPRA

SERVIZIO: MATERIALI N.D.T LABORATORIES

PER SERVIZIO

SCALA 10:1 | DISEGNATO | CAPO DI GRUPPO | VERIFICATO | DATA 21-2-84

84·1263·0A



N.	DENOMINAZIONE	QUANTITA'	MATERIALE	NORME E OSSERVAZIONI

IND	MODIFICAZIONE	DATA	FIRMA

PROGETTO
VAK III MEI - B

TITOLO
SIGILLO SU TIE ROD

FINITURA
RUGOSITA' = √
oppure

TOLLERANZE GENERALI

H		0.1
oppure	0.01	0.001

FUNZIONAMENTO
t = p = vuoto
fluido

COMMISSIONE DELLE COMUNITA' EUROPEE
CENTRO COMUNE DI RICERCA
STABILIMENTO DI ISPRA

SERVIZIO
MATERIALI N.D.T. LABORATORIES

PER SERVIZIO

SCALA	DISEGNATO	VERIFICATO	
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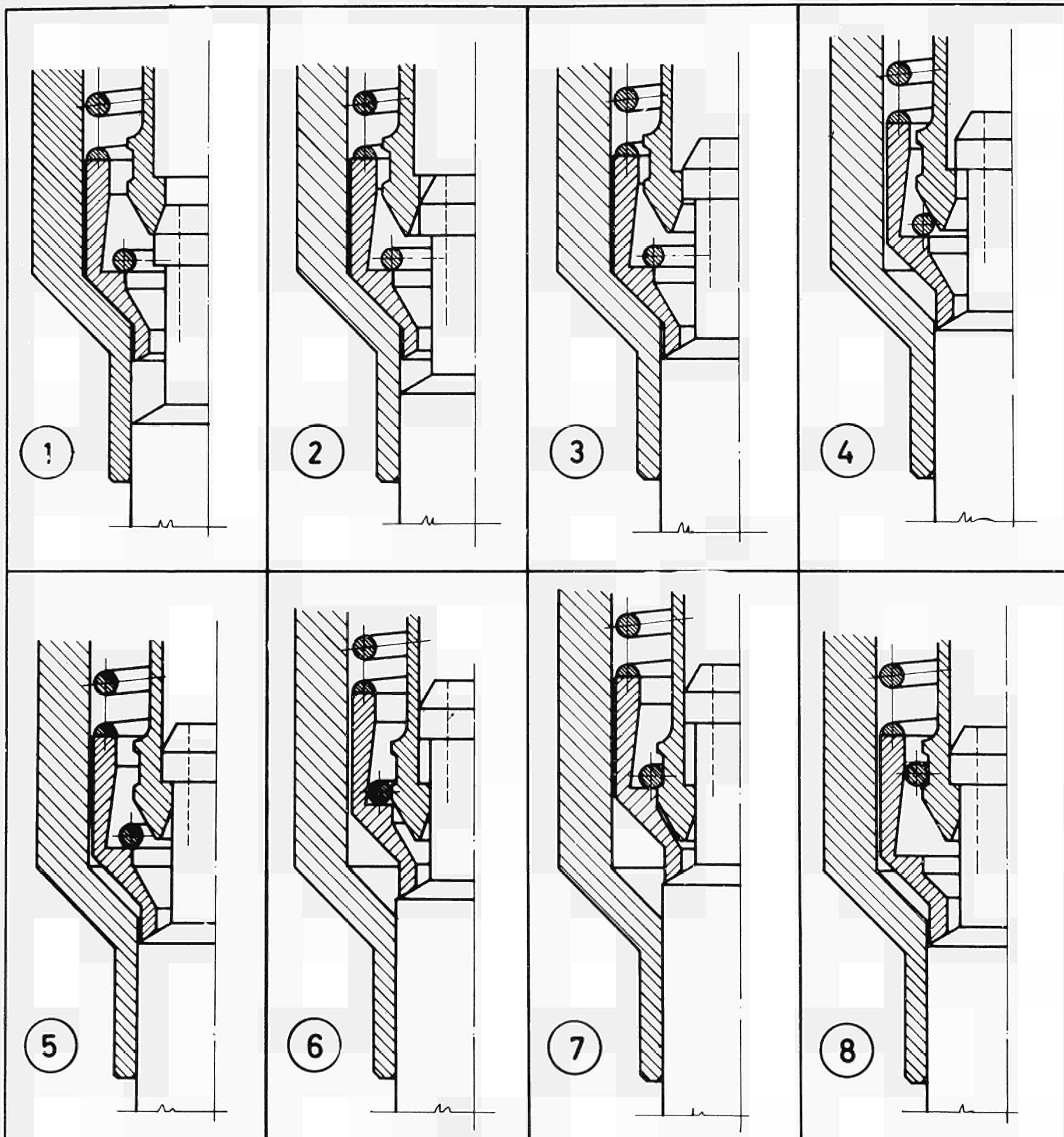

N.	DENOMINAZIONE	QUANTITA'	MATERIALE	NORME E OSSERVAZIONI

IND	MODIFICAZIONE	DATA	FIRMA

PROGETTO
VAK III MEI

TITOLO
FASI DI POSIZIONAMENTO DEL SIGILLO SUL TIE ROD

FINITURA — RUGOSITA' = √ oppure

TOLLERANZE GENERALI — 0.1 — 0.01 — 0.001

FUNZIONAMENTO

COMMISSIONE DELLE COMUNITA' EUROPEE
CENTRO COMUNE DI RICERCA
STABILIMENTO DI ISPRA

SERVIZIO
MATERIALI N.D.T. LABORATORIES

PER SERVIZIO

SCALA	DISEGNATO	VERIFICATO	
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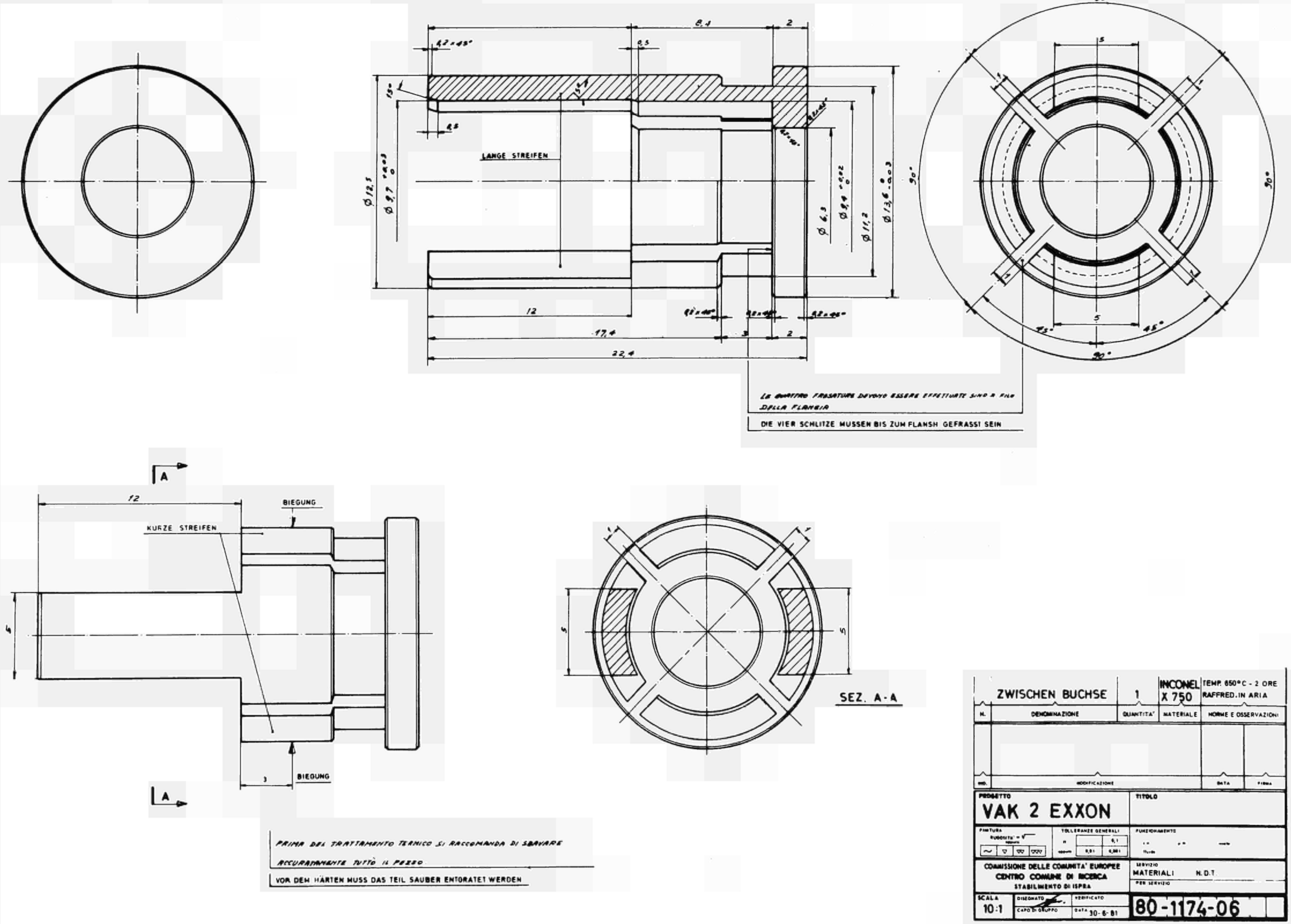


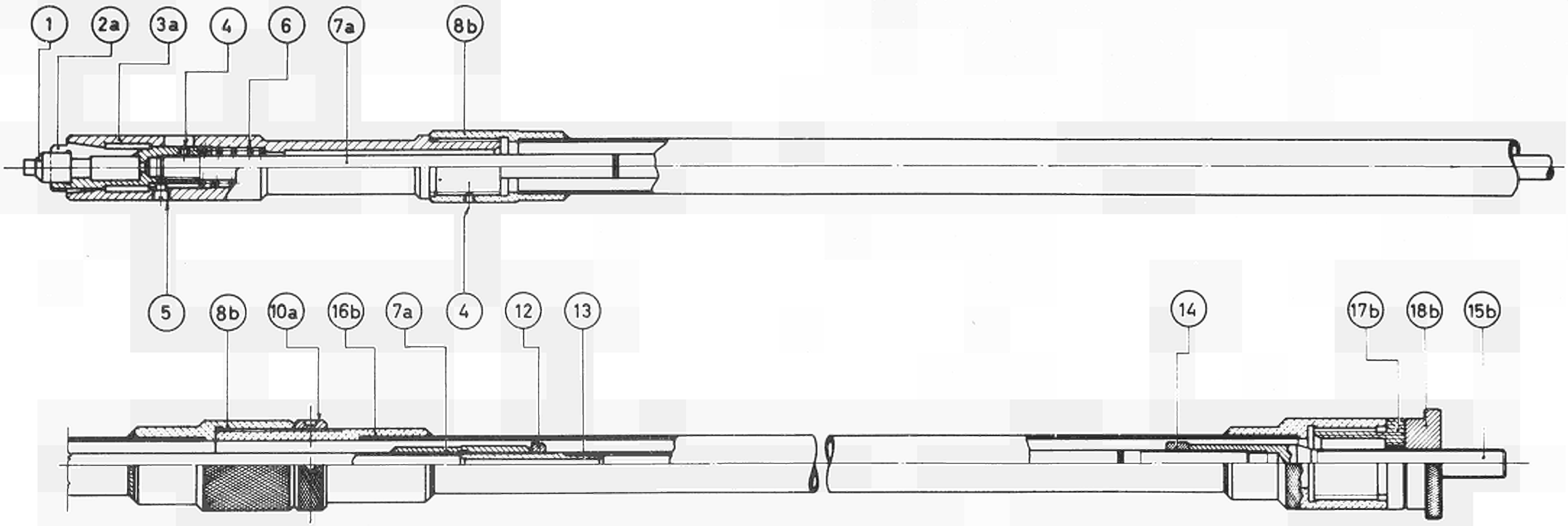
8,4
2
1,2 x 45°
0,5
15°
0,5
LANGE STREIFEN
Ø 12,5
Ø 9,7 +0,03 0
Ø 6,3
Ø 9,4 +0,02 0
Ø 11,2
Ø 13,6 0 -0,03
12
17,4
3
2
22,4
90°
45°
5
LE QUATTRO FRESATURE DEVONO ESSERE EFFETTUATE SINO A FILO DELLA FLANGIA
DIE VIER SCHLITZE MUSSEN BIS ZUM FLANSH GEFRASSI SEIN
A
12
BIEGUNG
KURZE STREIFEN
5
3
BIEGUNG
A
SEZ. A-A
PRIMA DEL TRATTAMENTO TERMICO SI RACCOMANDA DI SBAVARE ACCURATAMENTE TUTTÒ IL PEZZO
VOR DEM HÄRTEN MUSS DAS TEIL SAUBER ENTGRATET WERDEN
ZWISCHEN BUCHSE
1
INCONEL X 750
TEMP. 650°C - 2 ORE
RAFFRED. IN ARIA
N.
DENOMINAZIONE
QUANTITA'
MATERIALE
NORME E OSSERVAZIONI
IND.
MODIFICAZIONE
DATA
FIRMA
PROGETTO
VAK 2 EXXON
TITOLO
FINITURA
TOLLERANZE GENERALI
FUNZIONAMENTO
COMMISSIONE DELLE COMUNITA' EUROPEE
CENTRO COMUNE DI RICERCA
STABILIMENTO DI ISPRA
SERVIZIO
MATERIALI N.D.T.
PER SERVIZIO
SCALA
10:1
DISEGNATO
VERIFICATO
CAPO DI GRUPPO
DATA 30-6-81
80-1174-06

VAK III SEALS and SEALING SYSTEM

ANNEX II

Contents: Drawings

IX 71 918 0C
IX 72 929 0B
IX 72 929 03



N.	DENOMINAZIONE	QUANTITA'	MATERIALE	NORME E OSSERVAZIONI
18 b	POMOLO	1	ACCIAIO AISI 316 L	
17 b	GHIERA	1	TEFLON	
16 b	TUBO TERMINALE ESTERNO	1	ALLUM. AG 3 NE1	
15 b	TIRANTE	1	ACCIAIO AISI 304 L	
14	CONTRODADO	1	ACCIAIO AISI 304 L	
13	TUBO TERMINALE INTERNO	1	ALLUM.	
12	CONTRODADO	1	ACCIAIO AISI 304 L	
11				
10 a	CONTRODADO	1	ACCIAIO AISI 304 L	
9				
8 b	TUBO PORTA MANDRINO	1	ALLUM AG 3 NE1	
7 a	TIRANTE	1	ACCIAIO AISI 304 L	
6	MOLLA	1	ACCIAIO INOX.	
5	GRANO	1	ACCIAIO AISI 304 L	
4	GRANO 4MA x 5	2	ACCIAIO INOX.	UNI 2389
3 a	MANDRINO	1	ACCIAIO AISI 316 L	
2 a	PINZA	1	ACCIAIO AISI 420	TEMP. - RINV.
1	SIGILLO			

N.	MODIFICAZIONE	DATA	FIRMA
	ANNULLA E SOSTITUISCE I DIS N° IX-71-918-0A e 0B		

PROGETTO: PINZA PER POSIZIONAMENTO SIGILLI TIPO L.W.R.	TITOLO: ASSIEME
COMMISSIONE DELLE COMUNITA' EUROPEE CENTRO COMUNE DI RICERCA STABILIMENTO DI ISPRA	SERVIZIO: MATERIALI N.D.T. LABORATORIES
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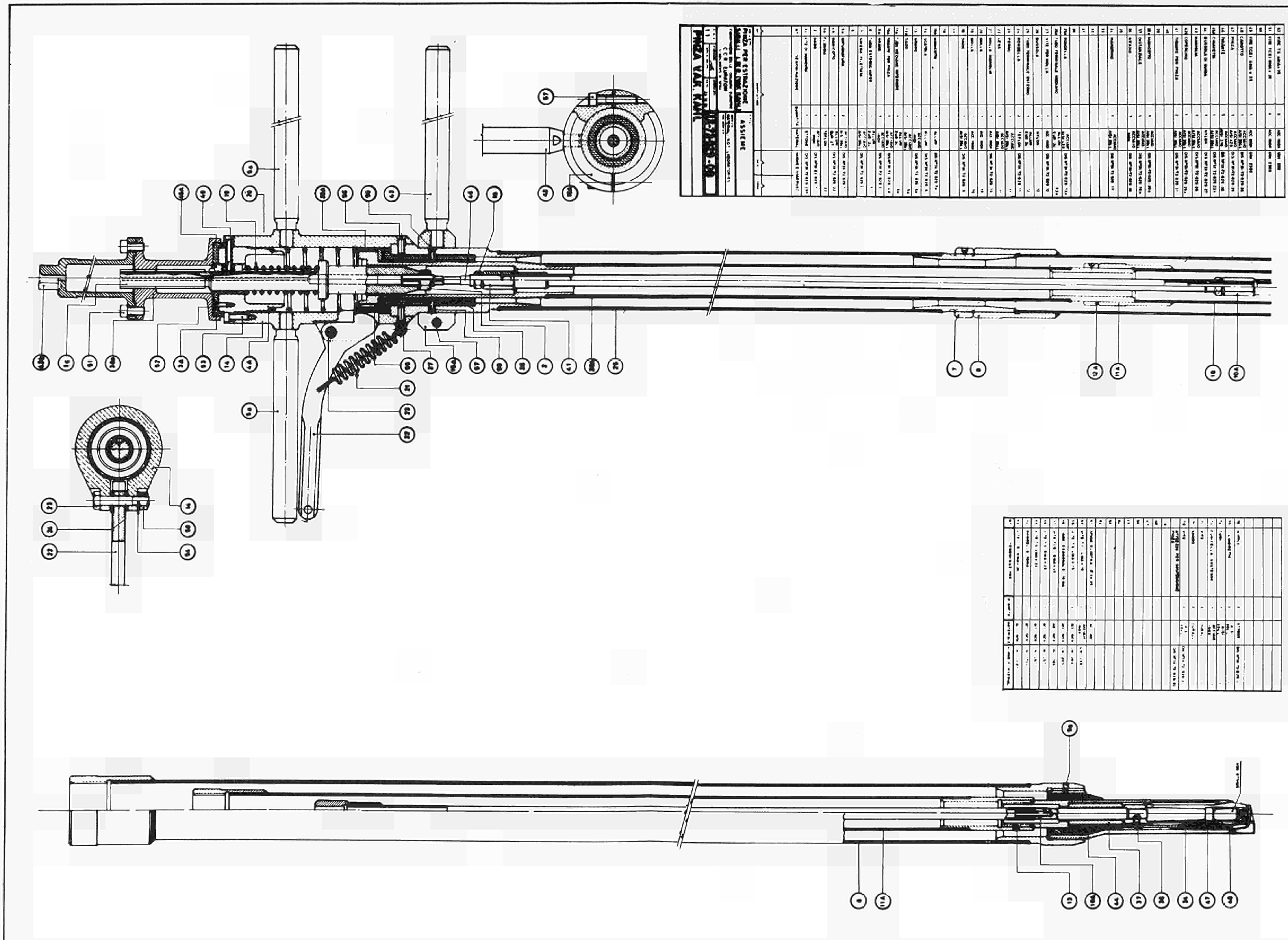
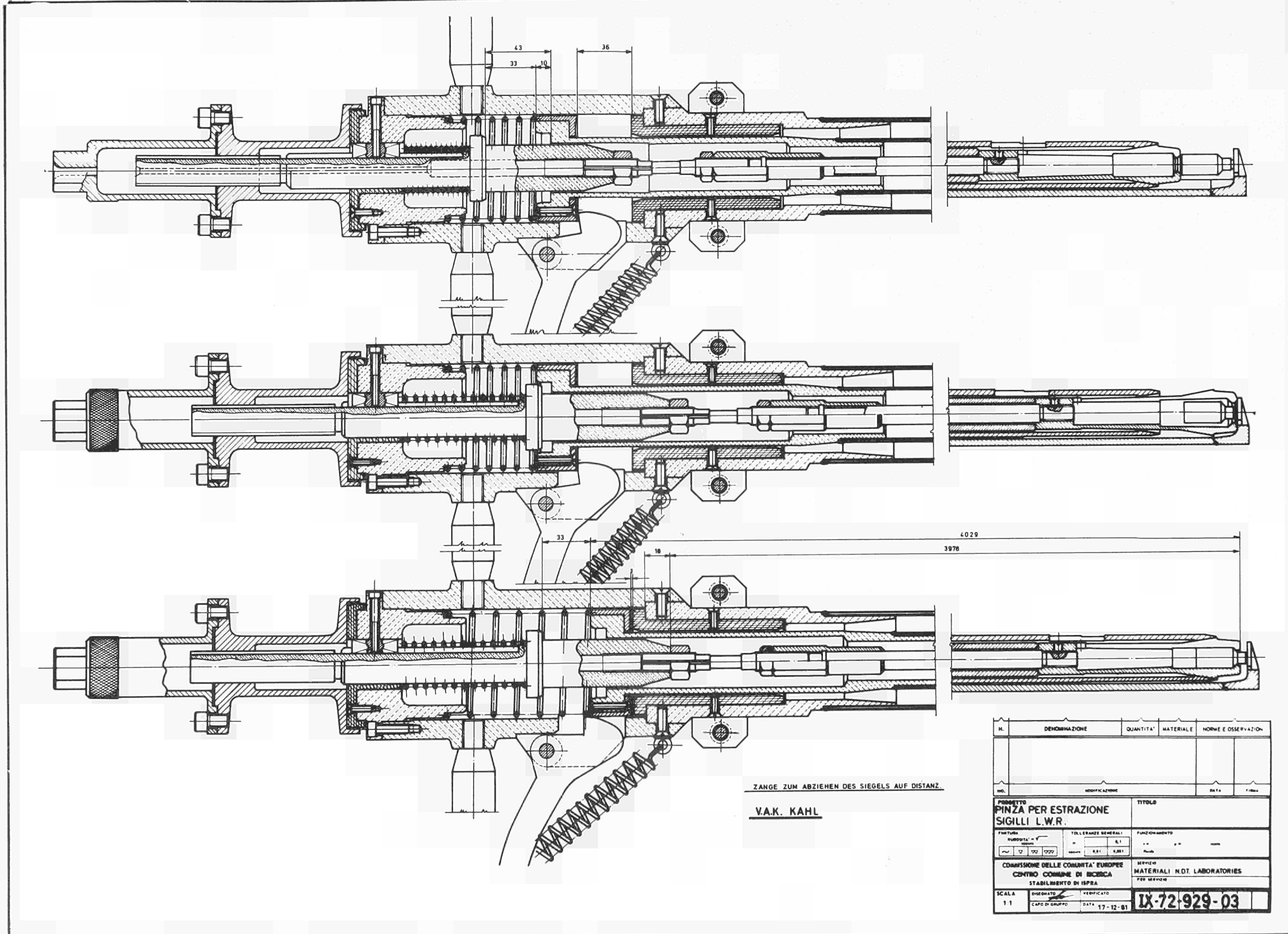

PINZA PER ESTRAZIONE
ASSIEME
PINZA VAR. KAHL

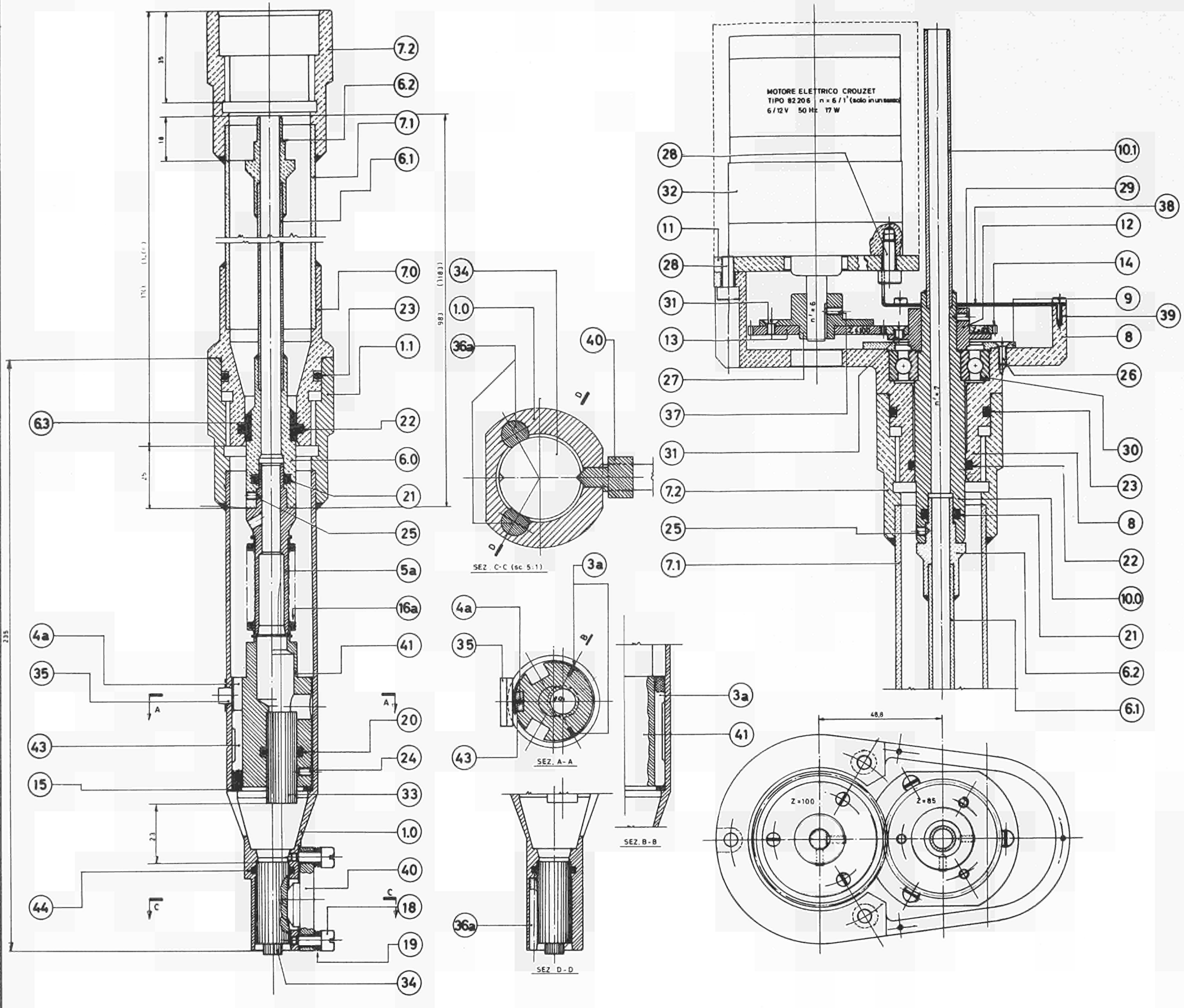

43
33
10
36
4029
3978
33
18
ZANGE ZUM ABZIEHEN DES SIEGELS AUF DISTANZ.
V.A.K. KAHL
N.
DENOMINAZIONE
QUANTITA'
MATERIALE
NORME E OSSERVAZION
MODIFICAZIONE
DATA
FIRMA
PROGETTO
PINZA PER ESTRAZIONE SIGILLI L.W.R.
TITOLO
FINITURA
TOLLERANZE GENERALI
FUNZIONAMENTO
COMMISSIONE DELLE COMUNITA' EUROPEE
CENTRO COMUNE DI RICERCA
STABILIMENTO DI ISPRA
SERVIZIO
MATERIALI N.DT. LABORATORIES
PER SERVIZIO
SCALA
1:1
DISEGNATO
VERIFICATO
CAPO DI GRUPPO
DATA 17-12-81
IX-72-929-03

VAK III SEALS and SEALING SYSTEM

ANNEX III

Contents: Drawings

83 12 45 0A
81 11 94 0A C



n	DENOMINAZIONE	QUANTITÀ	MATERIALE	NORME E OSSERVAZIONI
45				
44	ANELLO DI TENUTA OR 3062	1	GOMMA	DAL COMMERCIO
43	LAMELLA DI CENTRAGGIO	1	CELERON	-19
	ALESATURA SIGILLO			-18
41	CILINDRO PORTA TRASDUT.	1	ACCIAIO INOX	-17
40	CHIAVETTA	1	ACCIAIO X 700	-16
39	VITE T.C. 3MA x 6	3	ACCIAIO INOX	UNI 236
38	COPERCHIO	1	ALLUM.	-15
37	VITE S.T. 3MA x 7	2	ACCIAIO INOX	UNI 2054 B
36a	SPINA	2	ACCIAIO X 700	-13a
35	CONNETTORE PER CONTROLLO (PESO PRATICA)	1		DAL COMMERCIO
34	SIGILLO VAK			
33	TRASDUTTORE	1		DAL COMMERCIO
32	MOTORE ELETTRICO	1		DAL COMMERCIO
31	VITE T.C. 3MA x 6	6	ACCIAIO INOX	UNI 256
30	CUSC. A SFERE SKF 6203	1	ACCIAIO	DAL COMMERCIO
29	VITE S.T. 3MA x 7	2	ACCIAIO INOX	UNI 2054 C
28	VITE T.C.E.I. 3MA x 12	6	ACCIAIO INOX	UNI 2080
27	MOZZO INGRAN. MOTORE	1	ACCIAIO INOX	-14
26	VITE T.S. 3MA x 8	3	ACCIAIO INOX	UNI 256
25	VITE S.T. 3MA x 5		ACCIAIO INOX	UNI 2086
24	VITE S.T. 3MA x 6	1	ACCIAIO INOX	UNI 2086
23	ANELLO DI TENUTA OR 3037		GOMMA	DAL COMMERCIO
22	ANELLO DI TENUTA OR 3081		GOMMA	DAL COMMERCIO
21	ANELLO DI TENUTA OR 42		GOMMA	DAL COMMERCIO
20	ANELLO DI TENUTA OR 48	1	GOMMA	DAL COMMERCIO
19	PALLA SCRIGNA	12	ACCIAIO	DAL COMMERCIO -11
18	PERNO	2	ACCIAIO INOX	-11
16a	SOFFIETTO	1	ACCIAIO INOX	DAL COMMERCIO -10a
15	RONDELLA	1	CELERON	-09
14	INGRANAGGIO ALBERO Z=85	1		DAL COMMERCIO PVC -08
13	INGRANAGGIO MOTORE Z=100	1		DAL COMMERCIO PVC -08
12	MOZZO INGR. ALBERO	1	ACCIAIO INOX	-13
11	FLANGIA	1	ANTICORODAL	-07
10.1	TUBO	1	ACCIAIO INOX	-07
10.0	ALBERO	1	ACCIAIO INOX	-07
9	FLANGIA	1	ANTICORODAL	-06
8	SCATOLA MOTORE	1	ANTICORODAL	-06
7.2	MANICOTTO SUPERIORE		ALLUM.	-05
7.1	TUBO		ALLUM.	-05
7.0	MANICOTTO INFERIORE		ALLUM.	-05
6.3	BUSSOLA	1	NYLON	-04
6.2	RACCORDO SUPERIORE		ALLUM.	-04
6.1	TUBO		ALLUM.	-04
6.0	MANICOTTO		ALLUM.	-04
5a	MANICOTTO DI RACCORDO	1	ACCIAIO INOX	-03a
4a	PASTIGLIA MAGNETICA	1	[illegible]	-20
3a	LAMELLA DI CENTRAGGIO	2	CELERON	-02a
				-
1.1	MANICOTTO	1	ACCIAIO INOX	-01a
1.0	CORPO DISPOSITIVO	1	ACCIAIO INOX	DIS. N° 83-1245-01a

IND.	MODIFICAZIONI	DATA	FIRMA
4	ANNULLA E SOSTITUISCE IL DIS. N° 83-1245-0A	20-3-84	[signature]

PROGETTO: DISPOSITIVO PER IDENTIFICAZIONE SIGILLI VAK

TITOLO: **ASSIEME**

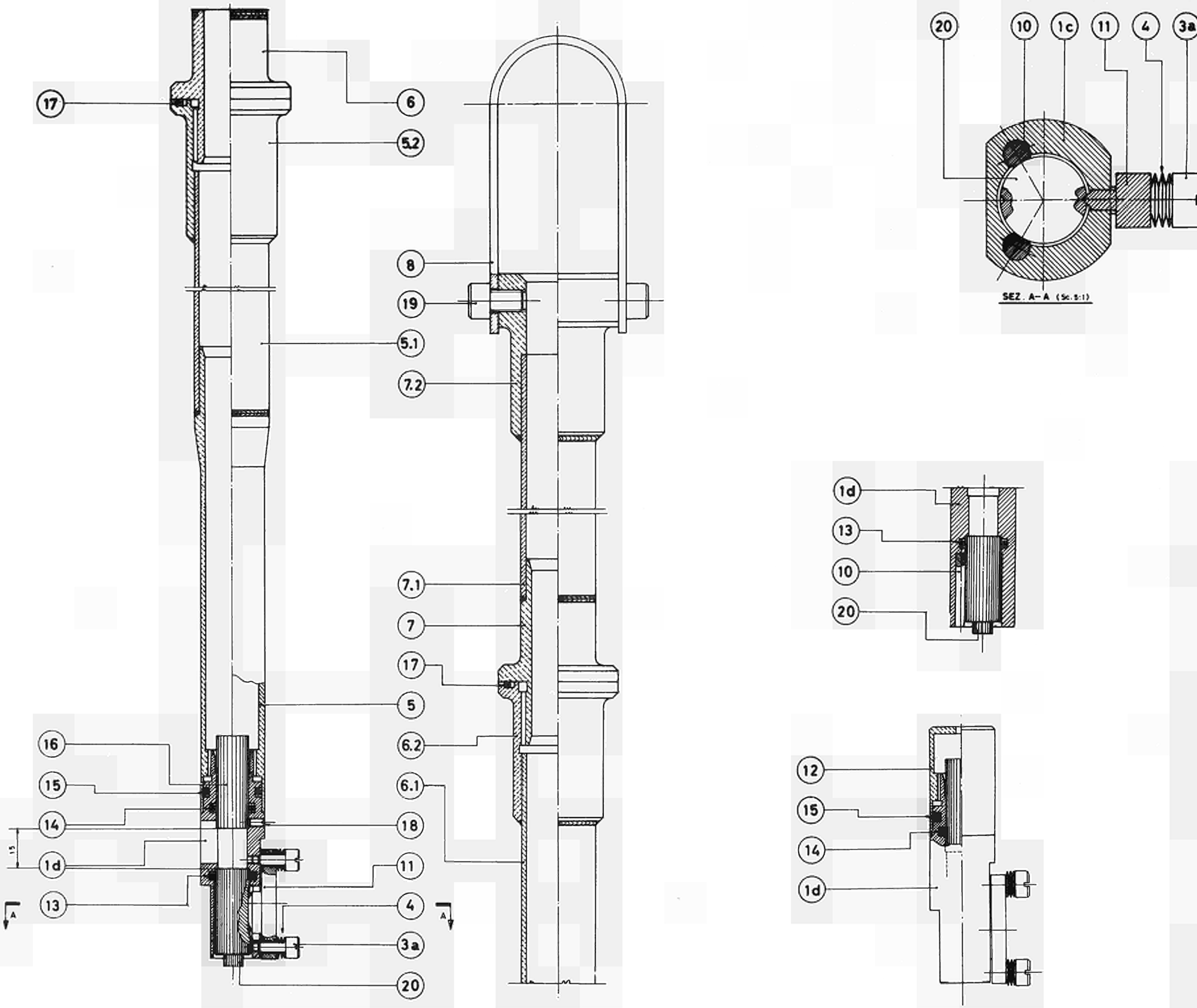
COMMISSIONE DELLE COMUNITA' EUROPEE
CENTRO COMUNE DI RICERCA
STABILIMENTO DI ISPRA

SERVIZIO: MATERIALI N.D.T. LABORATORIES

SCALA 2:1

DATA 20-3-84

83-1245-0A a



N	DENOMINAZIONE	QUANTITÀ	MATERIALE	NORME E OSSERVAZIONI
20	SIGILLO VAK III MEI	-	-	- -
19	VITE T.C.E.I. 8 MA x 12	2	ACCIAIO INOX	UNI 2389
18	VITE S.T. 8 MA x 6	1	ACCIAIO INOX	UNI 2186
17	ANELLO DI TENUTA OR 2137	2	GOMMA	DAL COMMERCIO
16	TRASDUTTORE	1	-	DAL COMMERCIO
15	ANELLO DI TENUTA OR 2068	1	GOMMA	DAL COMMERCIO
14	ANELLO DI TENUTA OR 113	1	GOMMA	DAL COMMERCIO
13	ANELLO DI TENUTA OR 117	1	GOMMA	DAL COMMERCIO
12	TAPPO	1	ALLUMINIO	07 bis
11	CHIAVETTA	1	INCONEL X 750	- 11
	RETTIFICA SEDE TRASDUTTORE	-	-	- 09
10	SPINA	2	INCONEL X 750	- 08
8	ANSA DI AGGANCIO	1	ACCIAIO AISI 304L	- 06
7.2	MANICOTTO	1	ALLUMINIO	- 05
7.1	TUBO	1	ALLUMINIO	- 05
7	MANICOTTO FILETTATO	1	ALLUMINIO	- 05
6.2	MANICOTTO SUPER	1	ALLUMINIO	- 04
6.1	TUBO	1	ALLUMINIO	- 04
6	MANICOTTO	1	ALLUMINIO	- 04
5.2	MANICOTTO SUPER	1	ALLUMINIO	- 03
5.1	TUBO	1	ALLUMINIO	- 03
5	MANICOTTO	1	ALLUMINIO	- 03
4	MOLLA SCHNORR E x 4,2 x 8,5	12	ACCIAIO (COMMERCIO)	DAL COMMERCIO -02-b
3a	PERNO	2	ACCIAIO AISI 304L	-02-b
1d	CORPO APPARECCHIO PORTA TRASDUTTORE	1	ACCIAIO AISI 304L	Dis.n°81-1194-01-c

IND.	MODIFICAZIONE	DATA	FIRMA
c	ANNULLA E SOSTITUISCE IL DIS.N° 81-1194-0A-b	23-3-84	[signature]

PROGETTO: APPARECCHIO PER CONTROLLO INTEGRITÀ VAK III (MEI)	TITOLO: ASSIEME
COMMISSIONE DELLE COMUNITA' EUROPEE CENTRO COMUNE DI RICERCA STABILIMENTO DI ISPRA	SERVIZIO: MATERIALI N.D.T. LABORATORIES
SCALA 2:1 (5:1) — DATA 23-3-84	81-1194-0A- c

VAK III SEALS and SEALING SYSTEM

ANNEX IV

Contents:

RECENT PRACTICAL SAFEGUARDS EXPERIENCE WITH THE NEW VERSION OF THE LWR (VAK) SEAL

B.C. d'Agraives, G. Dal Cero, R. Debeir, E. Mascetti, J. Toornvliet, A. Volcan

Commission of the European Communities, Joint Research Centre

Ispra Establishment, 21020 Ispra (Va) - Italy

ABSTRACT

This paper describes a practical experience gained during the past years by the Ispra team involved in the task of developing and applying an ultrasonic technique to the safeguards of such LWR fuel assemblies as the ones used at the VAK experimental facility of Kahl (FRG). The work is conducted in the framework of an Ispra support to the IAEA/FRG support programme (Task D3) and should lead to the selection, on an experimental basis, of procedures to be used in the broader context of safeguarding other LWR plants. It consists in the preparation and the implementation of demonstration campaigns during which seals built and sealing procedures studied in our laboratory are then field tested. It means that identification and reidentification operations are performed in conditions similar to those of future inspections, after the seals have been clamped on the fuel assemblies in near to real situations. The basic requirements as stated at the beginning, the actual on-site difficulties, the revised solutions, the results and their limitations will be reported. A panacea fulfilling all the original wishes can hardly be found. Nevertheless, with the experience being gained and with an improving exchange of views between inspectors, fuel manufacturers, plant operators, seal and sealing tools builders, reasonable and reliable operation solutions can be offered to the Safeguards authorities.

1. INTRODUCTION

The present contribution is aimed at a description of actual research and development work in the field of ultrasonic sealing techniques. In the recent years, large efforts have been devoted at JRC Ispra in order to improve such techniques which are characterized by their multidisciplinary aspect and by the fact that they are of concern to various authorities or organizations more or less directly involved in the safeguarding of nuclear materials and in particular to fuel assemblies. Thus, in such activities, there are roughly two sorts of problems: the ones raised by the very nature of things (we will call them "T" problems) and phenomena, and those raised by people or organization goals (we will call them "P" problems). Obviously, the whole of the reported work has started with the wish (or necessity) to fulfill Safeguarding requirements for LWR fuel assemblies. In fact, the work is part of the contribution of the Joint Research Centre (JRC Ispra) to the IAEA/FRG support programme of the Federal Republic of Germany (Task D3) and it has been broadly described in /1/. In this context, the Ispra part consists essentially of the study and the development of practical ultrasonic sealing techniques to be used as a verification and identification means in Containment and Surveillance Safeguards Inspections.

The sealing techniques developed at Ispra were first based on the original principle of a seal embodying internal marks, to be read by an external transducer, hopefully capable of seeing a sufficient portion of the seal when put in front of it, at a well determined distance from its upper edge. The solution was found to be promising at the laboratory level and the project of a cap-seal - to be clamped on the upper part of a fuel assembly - started with "VAK" seals, named after the experimental nuclear Versuchsatomkraftwerk facility at Kahl (FRG), where experimental and demonstration campaigns take place periodically. It was an elegant solution offering an easy-to-operate procedure, because the transducer holder was very simple, requiring no moving parts, contrary to the very first idea /2/, and also because the internal marks which were embodied into the seal itself, in an unchangeable manner, were considered as a fulfillment of the basic requirement of protection against alteration. It is interesting to notice that, at that time, the Sandia National Laboratories, Albuquerque, which are also very active in developing ultrasonic seals for fuel assemblies (FAID), had considered and adopted that very concept as a first solution /3/.

All the experience gained with the VAK seals at JRC Ispra measures the effective distance between laboratory test results and actual operativeness of a complete system such as a sealing system.

2. BACKGROUND

Essentially, in the first proposed solution, the seal presented itself as a cylindrical stainless steel object, about 0.5" in diameter and 1" in height. It was to be fastened on top of a rod - thus its name of cap-seal - to prevent loosening a nut (KWU F.A. situation) or rotating by 90° a special locking-sleeve (6x6 Exxon F.A. situation), which are the first operations done while disassembling fuel bundles according to normal specifications; for instance: when the substitution of one or more fuel-rods is requested. Such a small thing, a 5th of a cubic inch in volume, was supposed to protect a valuable item - 10,000 times bigger - such as a fuel assembly full of fissionable material, by forbidding any unpermitted dismounting. To do this, it would have featured a particular irreversible mechanism such as to allow an easy clamping, but also make its removal impossible without a detectable breakage.

The basic Safeguards requirements, usually expressed as:

- having an identifiable and stable unique random signature, and
- providing a clear and doubtless representation of its integrity,

should have been the first to be met. Unfortunately, to these fundamental problems (Class T) were added, very soon, other Class P problems. It means other requirements, asking for the seal to be insensitive to heat, thermal shocks, mechanical shocks, corrosion, vibrations, ageing, etc.

Before deserving any appellation of "seal", the "alien" had to display numerous qualities, not directly related to the previously mentioned basic ones. Above all, from the very beginning of the story, a most stressing requirement has been the size. In fact, everybody was to accept the presence of the seal - more or less reluctantly - upon one condition: it must be as small as possible, and even smaller! Fortunately, there was a limitation, i.e.: the necessity to see it and to seize it under meters of water while performing checks with handling tools. It is easy to understand that putting different items like a grip, a spring, internal marks and other integrity devices into a very small piece would have raised difficulties. A first consequence of this was the difficulty of putting enough marks inside the seal. The room provided for installing the internal grip and its spring was defined by material resistance laws and the size of the tie-rod extension on which to clamp the seal. The drawing in Fig.1 was given in /4/ and shows the first VAK I seal mounted on a KWU extended tie-rod. The room for putting the braze is the gap between piece number 1 (lid) and piece number 2 (housing). This first version was found to offer insufficient reproducibility of its signature.

The next version (VAK II) was designed for application on both KWU 9x9 or Exxon 6x6 fuel-assemblies. In the second situation, its introduction into the extended tie-rod end was to be preceeded by a special bushing having the purpose to lock the rotating sleeve (Fig.2a). But apart from its length, which was increased from 23 mm to 33 mm, little was modified in the drawings and the acceptation by the German technical inspectorate (TUV, Bayern) was obtained. Nevertheless, the cylindrical room available to put random marks was doubled and reproducible results as for the identity takings were obtained during laboratory screening tests, so as to encourage a first batch of industrial production at the Nukem Company (FRG). The reproducibility was acceptable, but the

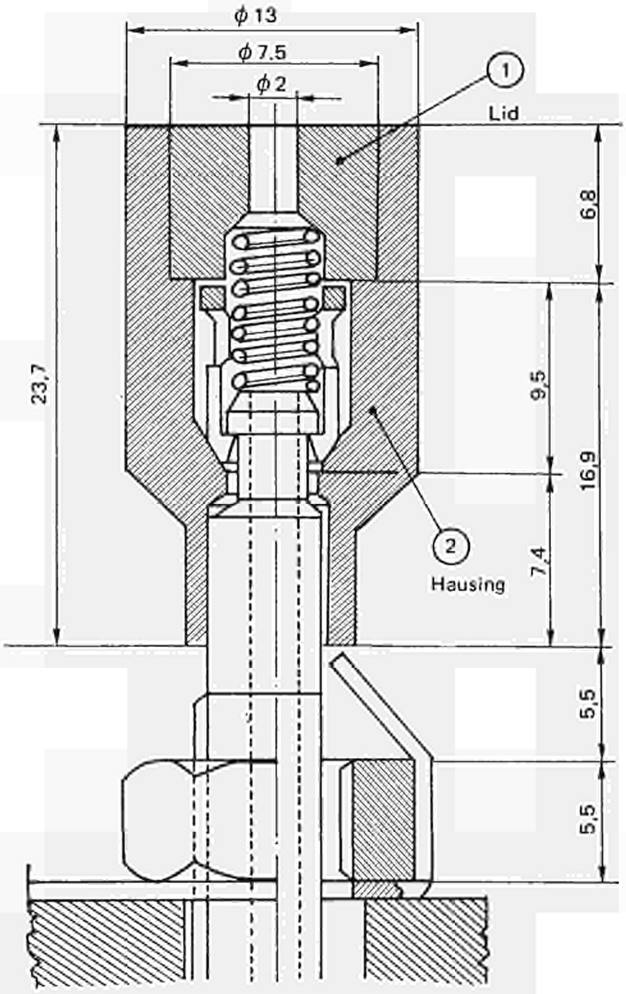


Fig.1 - The first VAK I seal.

system was working close to boundary conditions, because of the small size of the internal defects and due to the necessity of working with very high gains (90 dB), in order to "enter" into the seal. As a matter of fact, both changes due to temperature variations and to the interchange of transducers were found to have an effect on the reproducibility of the echoes patterns. These difficulties (Class T) finally resulted in giving sometimes fair and sometimes poor verification of previously identified seals. The interpretation of the signatures obtained from the Sonic instrument CRT on Polaroid photograms appeared to be uncertain, even to skilled people. It was understood that, even with correctly built VAK II seals, the size of the defects (vacancies in the braze) together with the very fact that a central transducer had to "see" all the defects at a "glance" would have asked for an exceptionally high precision not available in field conditions.

Thus, an attempt to propose other seals with external cuts in order to get strong "first echo" identities, was made. The central hole of some of the existing VAK II seals were drilled up the upper part with 4-5 different bits provided with a special square point, so as to obtain a stair shape

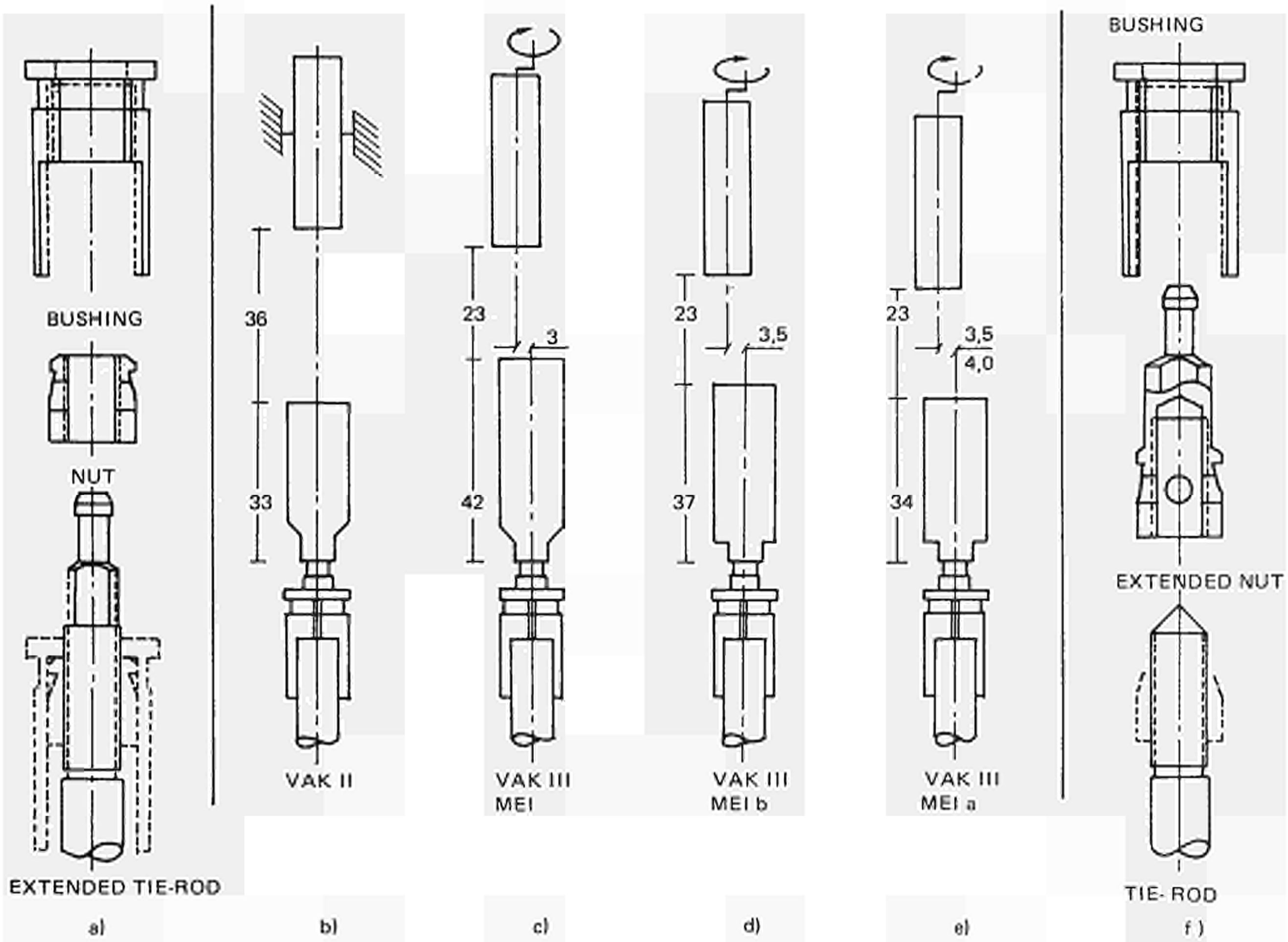


Fig.2 - Evolutions of the VAK seal.

with unknown step size. This external marking process was not extensively studied from the randomness point of view, but was rather to be used for the assessment of an automatic process to identify seals. Such strong marks were giving a better reproducibility on photograms and a procedure using a TV camera to read the photogram, then a computer to digitize the acquired image and memorize the data was studied by July 1982 /5/. In such a method, a characteristic curve from the CRT

$$x = f_j^n(t)$$

was obtained from a seal: j, in experimental conditions: n, depending on the date, the transducer, the place, etc. (n can be a number for a specific experiment). The curve was stored in the computer memory, and when performing comparisons, another curve:

$$y = f_k^m(t)$$

was considered, so that comparisons between the two curves could be made. We did correlation calculations, using a FFT (Fast Fourier Transform) and we obtained another kind of function:

$$R = r(s)$$

where r was the Bravais-Pearson coefficient of correlation calculated as:

$$r = \frac{\Sigma(x-\bar{x})(y-\bar{y})}{(\Sigma(x-\bar{x})^2\Sigma(y-\bar{y})^2)^{1/2}}$$

for different values of shifts: s, from -100% to +100% of the curves duration. The maximum value reached by r: r_{max} was then taken into consideration for determining which situation - or statement - was correct: "same seal" or "different seals". If r_{max} was near to 1, the signatures were considered as coming from the same seal. If r_{max} was nearer to zero, the signatures were considered as coming from different seals.

An attempt to formalise the problems raised by such comparison between two curves:

$$Diff_{j,k}^{p,q} = \| f_k^q(t) \| - \| f_j^p(t) \|$$

was discussed in /6/. It was underlined that the very problem was to have any symbolic differance of the kind:

$$Diff_{j,j}^{n,o}$$

neglectable in front of any difference:

$$Diff^{n,n}_{j,k}$$

and also, in front of any difference:

$$Diff^{n,o}_{j,k}$$

It was also stated that two means could be contemplated to reduce the effects of the undesirable differences:

$$Diff^{n,o}_{j,j}$$

which represents the problem of the reproducibility of an identification between verification 0 (Phase 0) and verification n (Phase n). One means was to improve still more the study effort with respect to ultrasounds and transducers, in order to reduce the experimental errors. A second means was to refer to a large statistical approach which would have hidden our ignorance of some parameter effects among a great amount of data with which it was possible to play. As a matter of fact, we will see that this has been currently used.

Once we gained the conviction that developing external marks would have raised other Class P problems and that keeping the internal marks as they were used so far would have raised many other Class T problems, we decided to go for a complete replenishment of the seal. We were encouraged to do this also because some vulnerability tests performed at KFK Karlsruhe had shown (only on a VAK I seal with a central hole) that such a seal had no actual protection against tampering. Obviously, we had to stick as far as possible to the existing dimensions and to use the same clamping mechanism for the attachment of the seal on the tie-rod end. The points on which we had to work out a solution were:

1) find a stronger random internal marking;
2) find a solution for the evidence of integrity;
3) design a new tool for taking identity records, useable in both laboratory and in-field tests;
4) study a better procedure for the performance of comparisons - or correlation - calculations.

The first two Class T problems were pertinent to the field of ultrasounds but also to the field of mechanics because of the necessity (again) to put as many features as possible in a small space. The third one was typically dealing with mechanics. The forth one asked for computation and reflection on their actual significance with respect to the decisions to be taken while performing identification processes.

3. ULTRASONIC IMPROVEMENTS

We will see in this section the approach we followed to improve the built-in markings in the seal. The very first problem was to build stable, randomly distributed, strong marks. After numerous attempts, we came down in favour of a so-called internal-external marking process: It means that marks are externally worked out of solid pieces such as small disks. The pieces are then assembled one upon the other in a compact stack which is brazed together with a circumferential container, thus the name internal. Using an amount of braze which is insufficient to fill completely all cavities, they keep a volume free of braze which creates a vacancy of unpredictable size and position. The exact configuration of the VAK III MEI (Marquage Externe Interne = Internal External Marking) has been recently given in /7/, but what we wish to underline here is the limitations we were faced with. As the pieces were mechanically cut, the slots were limited to about 1 mm width. Which reduced the number of slot per disk to one or two. The number of the disks in a stack was limited by the height of the room available in the upper part of the seal. So, we were limited to a number of about 12 cavities per seal. Due to another limitation, i.e. the transducer "depth-of-field", the stack could not be made very much higher than 10 mm (Fig.4). That limitation was coherent with the Class P requirement to keep the seal as short as possible! Conversely, should it be possible to increase the seal diameter, we would have space enough to put more slots - thus more cavities - into the seal, with no necessity to increase its height. Thus, a larger exploration radius (which determines the rotation of the transducer with respect to the seal axis) would have made easier the transducer holder (identification tool) design. But this was not permitted (Class P statement!). However, we succeeded, with gain levels of about 45 dB, in obtaining clear signatures with 4-8 large rounded peaks (Fig.5). As the transducer is rotated in front of the seal's upper edge, it "sees" the defects in the seal, one after the other (beyond a dead zone of about 6 mm). Their distance from the upper edge is not relevant, but their angular position and their amplitude are. The process is very similar to a conventional flaw detection. But the selected information is only the amplitude of the higher peak seen within a certain deepness range. The variation of that amplitude versus the angular position of the transducer represents the signature. As a matter of fact, the FTS Mark I Sonic instrument we used is provided with such an option (Flaw Amplitude Gate) which delivers an analog output, proportional to that amplitude. The random pattern

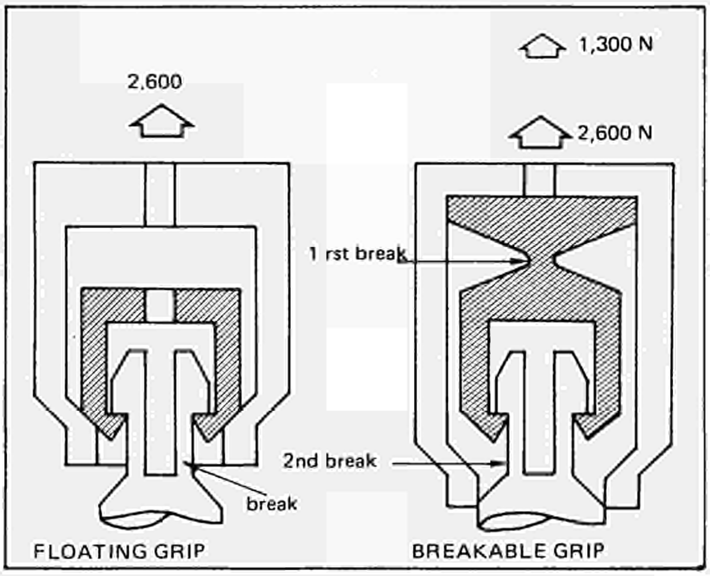


Fig.3 - Integrity evidence transferred from tie-rod to seal.

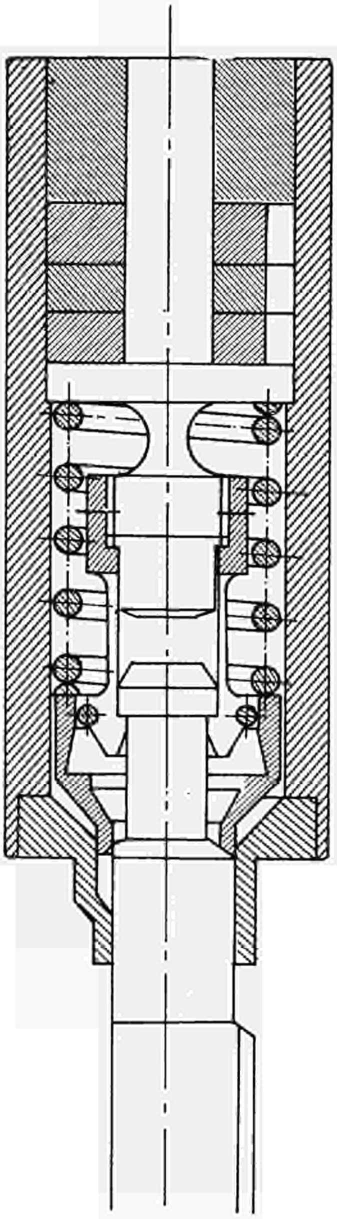


Fig.4 - VAK III MEI b seal.

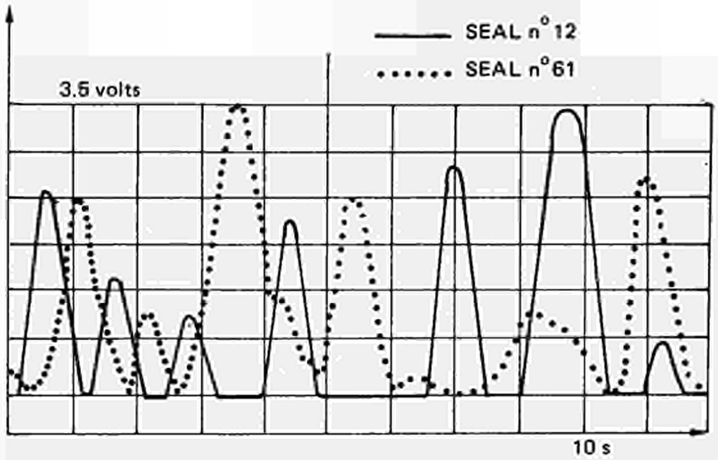


Fig.5 - Example of signature.

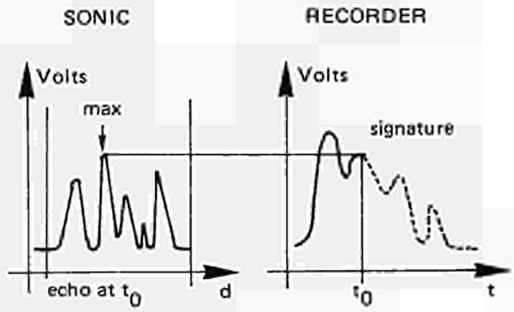


Fig.6 - Signature record.

is no longer the one of an ultracoustical echo as a whole. It is now given by the fluctuation of the reflecting capacity of the marks around the seal axis (Fig.6). Thus, we have put in the upper half of the seal a marking capable of reproducibility. Its dependence on temperature changes and with respect to the transducers interchange was also confirmed in the range 20-45°. Beyond the temperature of 45°, no changes were expected to occur, but we wanted to avoid damaging the transducers we had in a limited quantity. On the other hand, the temperature we found in the Kahl facility pound never exceeded 25°C even near the top of an irradiated F.A. Since, however, there was a request to explore a range up to at least 45°C, we have done this. As for the transducer interchangeability, only slight modifications on the peak shapes could be noticed, but not on their position in the signature.

The second above mentioned problem, i.e. the integrity evidence, appeared to be a less difficult task. In the previous seals, the grip destinated to seize the tie-rod end was a floating one (Fig.1). In the seal under consideration we did connect that grip to the upper part of the seal (Fig.3) through a rod provided with a breakable weak-link. Pulling the seal up for breaking the tie-rod end would have first resulted in breaking that link, which was designed for that purpose, and hence to "say" to the transducer that it is broken. An empirical approach led us to select something between a bi-conical and a toroidal shape. The rod in the middle goes through the disks stack up to the upper edge, acting as a wave-guide. For this check, the same kind of focused transducer has been used in the central position, exactly as we did before, with the static identification. Thus, we could use the existing tool with no modification. When the seal is unbroken, the CRT shows a first small echo corresponding to the ultrasound passage through the shrunk link, followed by a large one corresponding to the lower end of the rod. When the seal is broken, the small echo becomes very high and the second one vanishes.

A Class P requirement was to put the identification transducer and the integrity transducer in a same head. As the transducers are both 13 mm in diameter and since the one for the identity has to rotate on a 7 mm diameter circle, the requirement was momentarily abandoned for clear and mechanical reasons. Next to this, the clarity of the demonstration experiments in Kahl asked for separate tools to perform separate tasks. Having found ultrasonic solutions for both identity and integrity chekcs, we had to embody them in proper mechanical devices.

4. MECHANICAL ASPECTS

Once the concepts chosen for the identification marks and for the integrity evidence were found to work properly, a particular effort was put into building reliable mechanical solutions. A first point, related to the problem of integrity, was to propose a gripping device which would seize the tie-rod end easily. The grip and its jaws had to be kept practically unchanged with respect to the floating solution. Licensing authorities wanted that no new material be used. The system had to be safe, capable of supporting traction forces of about 2600 N with no re-opening possibilities. The inner clamping device had to break at about 1300 N (first breakage). The weak link, whose section was about 1.8 mm^2, had to support the thrust while pushing the seal down onto the tie-rod end. But the grip, and the spring responsible for keeping the seal steady, had to be protected against overheating during the further brazing process (about 1,100°C). To enhance the safety of the locking process, we thought of a special closing system which can be seen in Fig.4 in the "clamped" position. While the seal is installed, the jaws open, then go down, then close, and are seized externally by a small safety ring. Under the reaction of the main spring, which is compressed by the thrust-cup in the bottom, the seal goes up after the operator has released his pressure and the jaws go up, squeezed by the ring which wedges between cup and jaws, thus resulting in a perfect grasp of the tie-rod end.

During the extraction of the seal, the fracture link is first elongated, then broken; the seal goes up, pushes upwards the cup, which catches the tapered extremities of the jaws, which in turn become wedged into the lower part of the cup. The second traction can safely take place. The thrust-cup prevents the extraction of the broken tie-rod end. But, in any case, the fracture link indicates either a seal broken at the first stage, or completely extracted.

The second point pertinent to the mechanical aspect, was the one raised by problem number 3 mentioned above. The new identification tool had to be completely designed. In principle it had to fit a seal positioned on a fuel assembly and then provide a regular rotation of a transducer above that seal under identification. It was decided to use the same system both for laboratory tests (in a short configuration) and for in-field experiments (in long configuration). The concept was to keep the driving motor above and to transmit the rotation to the transducer holder through a shaft rotating into an external aluminium tube. The shaft and the tube had to be splitable into separate elements about 1.5 m long. For that tool, we were rather free as to its design, as no extreme requirements were imposed. We wanted to have the tool as light as possible and wanted the rotation of the transducer holder to be regular and linear. The lower part was designed with a rotating drum, having an excentrated hole to host the transducer. That drum could not use ball-bearings due to lack of room to place them and it had to rotate with no excessive play, no vibrations, in water. It was finally located in a cylindrical well, the sliding being ensured by three low-friction blades inserted in the drum. The drum was also connected to the transmission shaft through a bellow allowing flexion to take place but no torsion. The fitting between different sections of the shaft was carefully studied so that no additional play was added while using the long configuration. The first time that the new tool was used at the Kahl facility, it appeared to work properly. Unfortunately, during the decontamination process, the lower body and the drum were slightly damaged so that the rotation, for the experiments at Ispra, was found to have some vibrations. For this reason we decided to build a second unit.

As a matter of fact, after the campaign in November 1984 at the Kahl facility, we already thought of a further improvement of the VAK III seal which would have resulted in a shorter configuration but with a radius of exploration increased from 3 to 3.5 mm. Clearly, the drum head had to be re-designed and two new identical tools were built. One of them has been used successfully at Kahl during the recent experiments on May 22, 1984. So, it is interesting to observe that in the present matter, each time you modify your seal, you have to modify the drawings and to build new tools, partially or completely. You cannot afford to eliminate an older version as you will need it for further re-identification of the corresponding seals. It is advisable to seek a certain standardization in order not to fill the room in the reactor with plenty of tools!

The present procedure uses four different tools:

- a tool for placing the seal (and the reaction bushing) on the fuel assembly. It works for all VAK seals configurations, as they all have the same diameter. It stays in the reactor;
- a tool for checking the integrity. It is a single long tube which fits the seal axially. It would also work for identifying VAK I and VAK II seals if this was needed. It stays in the reactor;
- a tool for breaking the seals. It is heavier and more sophisticated as it embodies a section for measuring the breakage forces. Its lower grip has to be interchanged according to the extracted seal. It has been modified, on site, several times. It has always worked properly. It stays in the reactor;
- a tool for the identification as described above. The extreme sections: transducer-holder (down) and driving-motor (up) are brought back to Ispra, after each campaign. The intermediate extending sections are kept at the facility.

Another requirement, stated last year, was to seek for the performance of identification checks directly on the irradiated F.A., in the bottom of the pond. Yet, no attempt has been made to do this, but the identification tool is provided with sufficient extension sections so that it is possible to reach deeper locations. As for the handling by the inspector - or verifier - it could be less easy to work with a longer tool, but if the work could be done in loco without stripping the fuel assembly, the operators would save time. A step would be made towards the future automatic handling of the identification tools.

There emerged a more precise requirement for the identification of VAK III seals in dry conditions. The inspection authorities were thinking of a "for life" seal to be identified either in dry conditions, as for instance at the fabrication plant, or in under-water conditions, as it is normally done on irradiated fuel assemblies. We propose a method using the existing identification tool in its short configuration (no extension tubes), where a tight chamber is obtained by means of slight modifications. The bottom of that chamber gets closed by the seal itself which penetrates a rubber O-ring fixed into the chamber. Such a problem is typical of the Class P problems. It raises questions which are to be solved in common agreement by the developer, the manufacturer, the operator and the inspector. Starting from an existing device, the developer proposes a solution, but he needs information from the manufacturer about how, where and when such identification operation could take place in the plant. In our present case, we need to know whether the assemblies are available vertically or horizontally for the sealing operations. But the operator could ask for a "vertical" sealing and the manufacturer for a "horizontal" one. It is probable that the inspector will prefer the easiest solution or the most reliable one.

Finally, a question specific to the Exxon fuel assemblies was raised concerning the special extended tie-rod ends to be installed at the fabrication plant when a fuel assembly is to receive a VAK seal. That special modification requires some months pre-advice delay at the plant. The manufacturer would be very happy not to have to introduce such modification on its assays. So, we studied the possibility of screwing a special nut on the normal tie-rod end at the moment the assembly is closed (Fig.1f). Although we think to have a feasible drawing, we need - again - to receive information and agreement from the manufacturer as to the easiest and safest way to install such a special nut.

5. CORRELATION PROCESS

As far as ultrasounds and related mechanisms are concerned, we can say that a reliable method has been developed and demonstrated to build and read randomly marked seals, able to be clamped on and extracted from LWR fuel assemblies. Signal curves (Fig.5) have been plotted from similar identification experiments, performed with a same seal at Ispra and then at Kahl (Phase 0 and Phase 1) which were practically superimposable so that they could readily be interpreted as coming from the same seal.

An important problem to solve is the question of automatically identifying the seals. That question is a Class T question but also a Class P one, because it involves both objective research and subjective decisions. The problem lies in the differences - or errors - which always separate the random physical character being produced during an experiment, from its available representation. Should such a difference be negligible - or constant - in all possible circumstances, the graphs from all experiments would be superimposable (like a photocopy) and no difficulties would be encountered in recognizing their common origin. Mathematical tools, such as the coefficient of correlation, are available to issue a statement in such cases. But, unfortunately, these differences do change with circumstances and, generally, in an unpredictable manner. We have to face this instability in trying to reduce the error effects as far as possible. In particular we must be careful about the experimental instruments and the experimental procedure.

The present technology consists in performing the comparison between two signatures taken rather far from the occurring phenomenon they represent. As we cannot predict changes in the character under consideration, nor in the measuring chain, the only way out is to perform statistics as done at present, and to go on applying correlation processes. We have described our method in /7/ and /8/. The method we used had the main scope of demonstrating the feasibility of a conventional digitization, followed by a simple computation of the Bravais-Pearson coefficient. With the MEI marks we had no particular process to apply on the stored data. We had only to perform a shift of about +/-3% of the total signature length so as to compensate for mechanical re-positioning errors and in order to re-synchronize the signals properly. The method is schematically drawn in Fig.7.

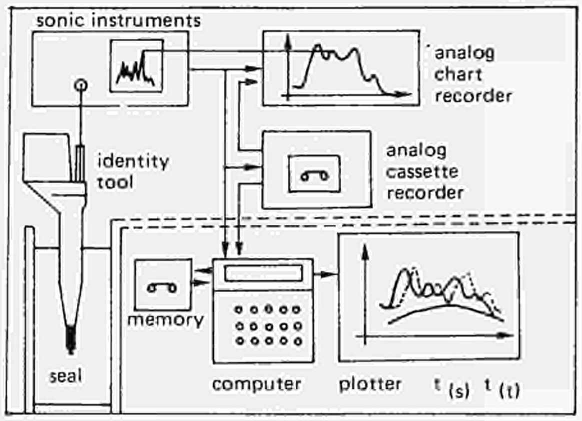


Fig. 7 - Instruments block diagram.

During the last campaign at Kahl on May 22, 1984, we had good results with 8 VAK III MEI b seals, which were installed, identified and re-identified on site, but the data were processed back to Ispra. Autocorrelation results are given in Table I, next page.

The 28 "cross-correlation" factors were ranging between -0.21 and +0.65 and 92% of them was ranging between -0.21 and +0.37.

Table I - Autocorrelation factors

Seal nb	12	13	14	15	16	18	19	20
x^{Ispra}_{Ispra}	.97	.98	.97	.93	.94	.93	.93	.97
x^{Kahl}_{Kahl}	.81	.96	.98	.98	.98	.86	.99	.94
x^{Kahl}_{Ispra}	.98	.95	.96	.97	.98	.77	.96	.98

On the same batch, tests on the independence from temperature have given 16 coefficients greater than 0.95 and tests on the independence from transducer change have given 23 values higher than 0.92 and one spurious value of 0.88. For these two spurious values of .77 (see table) and .88, we usually refer to a second estimator, i.e.: $R^+ = R/\bar{x}-\bar{y}$ which allows us to remove the doubt. If the seals are different, R^+ is low, if not, it tends to infinity.

Other estimators have also been tested and are mentioned in /8/. Other methods consist of working on the signal digitized data by performing smoothing, sampling, filtering, to get "sufficiently" high correlation coefficients. Obviously, they are used preferably when the outcoming signatures are not so much similar from one experiment to the other. They can be useful to eliminate unexpected noise added on a basic signal. But taking out a noise from a signal can also deprive it of its random nature.

It is important to underline that the methods to check an identity by a signature of the f(t) kind are available. The correlation factors or "error" estimators are valid and it is expected to have good probabilities of making a correct statement once the physical property giving the signature is sufficiently reproducible. Making numerous experiments is certainly a good approach to get an idea on how the populations of the "cross" and of the "auto" correlation are distributed. But another approach has to be considered. This is the estimation, through probability density functions, of the actual randomness of a particular type of mark, or signature; the relation between the correlation factor populations of a small tested batch and of a large unknown series of the same type and the effects of parameters such as: number of data, shift, expansion, drift, smoothing, averaging, filtering, etc. on the richness of a determined type of marking process. We can consider that the question should be discussed with Safeguarding authorities, within ad-hoc groups.

6. CONCLUSIONS

We have tried to review the problems raised by the development of an ultrasonic sealing device covering both those that have been solved completely and those that have only been partially solved. To do this, we have referred to a specific development related to the LWR fuel assemblies and to the so-called VAK seals, studied at JRC Ispra, in the framework of the FRG Support Programme to the IAEA. Throughout our technical description, an attempt has been made to separate two kinds of general problems or questions. We called "Class T" problems the ones concerned by the things themselves, i.e. related to the nature of the phenomena; and "Class P" problems, the ones coming from the wishes - or requirements - of operators or authorities, often without regard to the nature of the difficulties they raise from a technical point of view. It was shown to what extent they sometimes are compatible one with the other, and sometimes not.

While giving an illustration of the various disciplines involved: ultrasonics, mechanics, computation, we wanted to underline the necessity, for succeeding in such an R&D, of involving the different partners, and in particular the manufacturers, the operators and the Safeguarding authorities, at the very start of the development. It is desirable that the safeguard systems be considered as a part "in se" of the safeguarded items, in the future. It would avoid some misunderstanding about what is possible, and help to frame more exactly the tasks of the systems developers. This would be particularly true for the next generation of fuel assemblies, to be used in automatically controlled facilities.

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REF. 2

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FRG-IAEA TECHNICAL SUPPORT PROGRAMME. TASK D 3

Technical note to the intention of the Joint Working Group

STUDY AND DETERMINATION OF A SPECIAL INTERMEDIATE BUSHING TO BE USED AS A DISTANCE-PIECE WHEN EXXON XN-1 FUEL ELEMENTS WILL BE SEALED WITH VAK 2 SEALS

B.C.d'AGRAIVES, A.VOLCAN

1. Scope of the present study

Propose and realize a distance-piece compatible with the modified Exxon XN-1 F.A.Upper End Cap Tie Rod and the VAK 2 Ispra Cap Seal. The distance-piece having the main purpose to avoid the Upper Tie Plate of a sealed
(fig.1) (°) Fuel Assembly being mishandled or moved with respect to the Bundle, without breaking the Cap Seals.
Provide the Reactor Facility of Kahl (FRG) with a number of such distance-pieces equal to the number of Cap Seals which are planned to be installed, i.e. 72 .

2. Specific requirements

a/ The distance-piece should be fitted to the Cap Tie Rod so that it will be easy to put in and to pull out whether the Upper end of the Cap Tie Rod has been broken during Seal extraction operations or not.

b/ The distance-piece should resist the longitudinal force necessary to break the Tie Rod End during Seal Extraction operations. It has to be considered as a support for the U shaped base plate of the extracting tool.

c/ The distance-piece should be fitted to the Tie Rod, possibly with no additional parts like clamping screws, nuts etc...

d/ Once the distance-piece has been put in, rotation of the
(fig.1) Oval Locking Sleeve must be impossible. The Oval Locking Sleeve is positioned along the Tie Rod, from above by the Adjusting Nut and from underneath by the thrust of a light helicoid spring. The Locking Sleeve finds its locking position inside an oval hollow worked out of the upper part of the Tie Plate, after this last one has been pressed down and then released. Thus, the distance-piece must prevent any rotation of the Locking Sleeve, even after the Upper Tie Plate has been depressed.

e/ The material chosen for the distance-piece must be compatible with the operating conditions.

(°) Information in the margin refer to figures, drawings or documents given after the text and related to the topic in discussion in the front lines.

2. Specific requirements (cont'd)

f/ The distance-piece should keep steady during the Reactor operates normally.

g/ The design for the distance-piece should not require further changes in the Exxon Modified Tie Rod as defined by XN-NF-304,331. Neither for the Adjusting Nut or Locking Sleeve or Upper Plate dimensions and tolerances.

3. Proposed solution

3.1. First Version

Looking for an easy-to-manufacture, simple solution, it was suggested to have, as a distance-piece, a so-called: "Intermediate Bushing" ("Zwischen Buchse"), which would be elastically fastened around the Adjusting Nut cylindrical surface, by friction. Thus avoiding the use of any additional part like screw, pin or nut.

(fig.2) A first solution, consisting in a simple opening cylindrical ring provided with two legs was experienced and also demonstrated to the Group in Karlsruhe.

The way it works is as follows:

- Putting in:
  - (fig.1 + 80-1174-07) The Bushing is forced lightly onto the Adjusting Nut which tapered upper edge eases the insertion.
  - (fig.1 + 80-1174-00F + 80-1174-08) During insertion, the Bushing Legs penetrate into the room kept free in between the cylindrical Tie Rod and the oval Well machined out of the Tie Plate. Thus any rotation of the Oval Locking Sleeve is prevented, even if the Tie Plate is depressed.
  - (fig.1) Insertion ends when the internal flat surface of the Bushing enters into contact with the upper flat surface of the Adjusting Nut, thus offering a support for reaction during eventual further breakings of the Cap Seal.
- Extracting:
  - The upper collar of the Bushing is easily seizable with a simple tool (nipper), provided that the tool is

- Extracting (cont'd)

  not pressing the Bushing on the Adjusting Nut during the extraction. Thus the extracting force should be about the same as the putting-in force.

  - After extraction, the Bushing is kept attached to the Nipper up to a place where it can be separated with no risk of falling in the pool.

3.2. First experiments

(fig.3+ fig.4) A special bench was built to allow the measurement of the friction force necessary to insert or extract a simplified bushing (no legs, no collar) on and out of a normal Adjusting Nut provided by Exxon. It could work either in room conditions or in water at 250°C and 40 Bar.
Experiments performed either in hot or in room conditions have shown no sensible differences in the friction forces Bushing/ Nut. So it was decided to perform all experiments on a simplified bench, as presented to the Group in Karlsruhe. (fig.5)
It was also observed that "putting in" and"pulling out" forces were of the same order. Repeating the operations "in" and "out", with the same pair Bushing/Nut, was found to decrease a small amount the friction force. This because - and differently from the actual situation for which only one or two operations are planned - of the "running-in effect", when re-passing on the same position.

3.3. Results with first version

Starting from the tolerances declared by Exxon on the drawings, the Nut outer diameter is .360 $\pm$ .005 inch, or :

$$9.144 \text{ mm} \pm 0.127 \text{ mm} \quad \text{(exact)}$$

(test report) But, a batch of 20 nuts taken out of the 3,000 made by Exxon has shown a better quality (dispersion 2/1,000 or 0.018 mm), and Exxon people have indicated that most probably the dispersion in the outer diameter of the nuts will be actually of $\pm$ 0.01 mm.
Whereas no difficulties were found in making a bushing with a single longitudinal slot, keeping a reasonable friction

Results with first version (cont'd)

force on the Nut, with the tolerances actually found, it was difficult to adapt without deformation on a Nut specially made with the higher possible theoretical outer diameter of .3650 inch or 9.27 mm .
Also, the friction force was very small when putting the bushing on a Nut built with the smaller possible theoretical outer diameter of .3550"or 9.017 mm.
For the precision, the diameters we have used were:

d min = 9.010 mm
d nom = 9.160 mm
d max = 9.280 mm

During these tests it appeared that the extracting force for such a light piece, when handled directly or distantly by one operator, should be of about 50 ÷ 100 N. It is, in fact important that the force, when a long tool will be used, be sufficiently high to be sensitive to the operator.(°).

Different types and shapes deriving from the first version were studied and measured, with different bending rate given to the lips prior to put the pieces (Inconel 750) in heat
(fig.6) treatment (2 hours at 650°C). The one shown in the photograph down on the right, with 4 slot was then selected.

3.4. Second Version and Results

The second version is different from the first one as:

1/ The collar is rigid in place of being cut by a slot, thus increasing the handling possibilities and allowing to re-use an existing extracting tool in Kahl (the one for putting the seals in) (fig.1+ 80-1174-06)

2/ Four slots are machined, in place of one, thus allowing a better symmetry. Four lips are available: two are kept as from fabrication and bear the locating legs; two are to be lightly

(°) Approx. weight of a bushing: 5.5 grams

Second Version and Results (cont'd) 2/

bent toward the center, around a calibrated pin, in such a way that, after the heat treatment, they work like two opposite springs.

With respect to the first version, the second version has the same general dimensions.

The second version configuration was found to offer a better flexibility to adapt either on the maximum diameter (d max) or on the smaller one (d min).

After a series of different tests, the results were considered as acceptable when the following friction forces were obtained:

		in	out	
	on d min	40 N	30 N	
(fig.7)	on d nom	75 N	50 N	(room conditions)
	on d max	230 N	190 N	

When compared to other tests, these figures can be considered as typical.

These results were obtained with a pre-bending of the short lips, which were pressed onto a 8.2 mm diameter pin, as shown (fig.8) on the sketch, the internal diameter, at the lower extremity of the lips, being of 8.85 mm after the squeezing force was released.

The following heat treatment was then applied:

2 hours at 650°C and natural cooling in air.

No change of the internal diameter was observed after the heat treatment.

Generally, the bushings return to their original dimensions after mounting on Nuts with d min or with d nom.

After mounting on Nuts with d max, the internal diameter was found to be increased from 8.85 mm to 8.90 mm. But it is recalled that the probability to find such a Nut is extremely low and, even so, a bushing - once fastened to its Nut - would normally be used only with that particular Nut.

These results can be considered as facing correctly the requirements as mentioned on point a/ to g/ in page 1 and page 2.

Furthermore, the proposed solution, in second version, allows to use the same tool for:

- Putting the bushing in
- Putting the seal in
- Extracting the bushing

(fig.9) provided that the mandrel of the existing tool be modified by making a simple circular groove in the bottom of the gripping nippers.

The solution also is flexible in that it is ever possible to increase or decrease the friction force level, through an adjustment of the bending of the lips.
In the presented version the figures as on the Table in page 5 are valid.

The good functioning of the bushing were tested on an Ispra made mockup as shown on the photograph, in this report. (fig.2)
This mockup was built according to the available Exxon drawings.
Another mockup, representing the higher part of a Fuel Assembly (Tie Plate with its 8 locking rods) would be available by the end of August 1981, to perform eventual complementary tests.

3. Handling tool

As mentioned above, the handling tool is the same as the one used for putting the seals. The mandrel was removed from the Tool in Kahl, and modified at Ispra. Once installed again on the tool, no special operation is requested to pass from the sealing function to the "putting bushings" or "extracting bushings" functions.

4. Bushings fabrication

The fabrication was ordered at 1/7/81. (80 pieces)
(Nickel Contor + Cabot) Material as specified in the present report in fine.
Bending and preparation of the bushings is planned to be made for the beginning of September.

5. Acknowledgements

The authors wish to thank Mr. E. Mascetti for his active participation to the preparation of the experiments and the construction of prototypes used in the present study.

6. Figures and drawings

The following are available after the text:

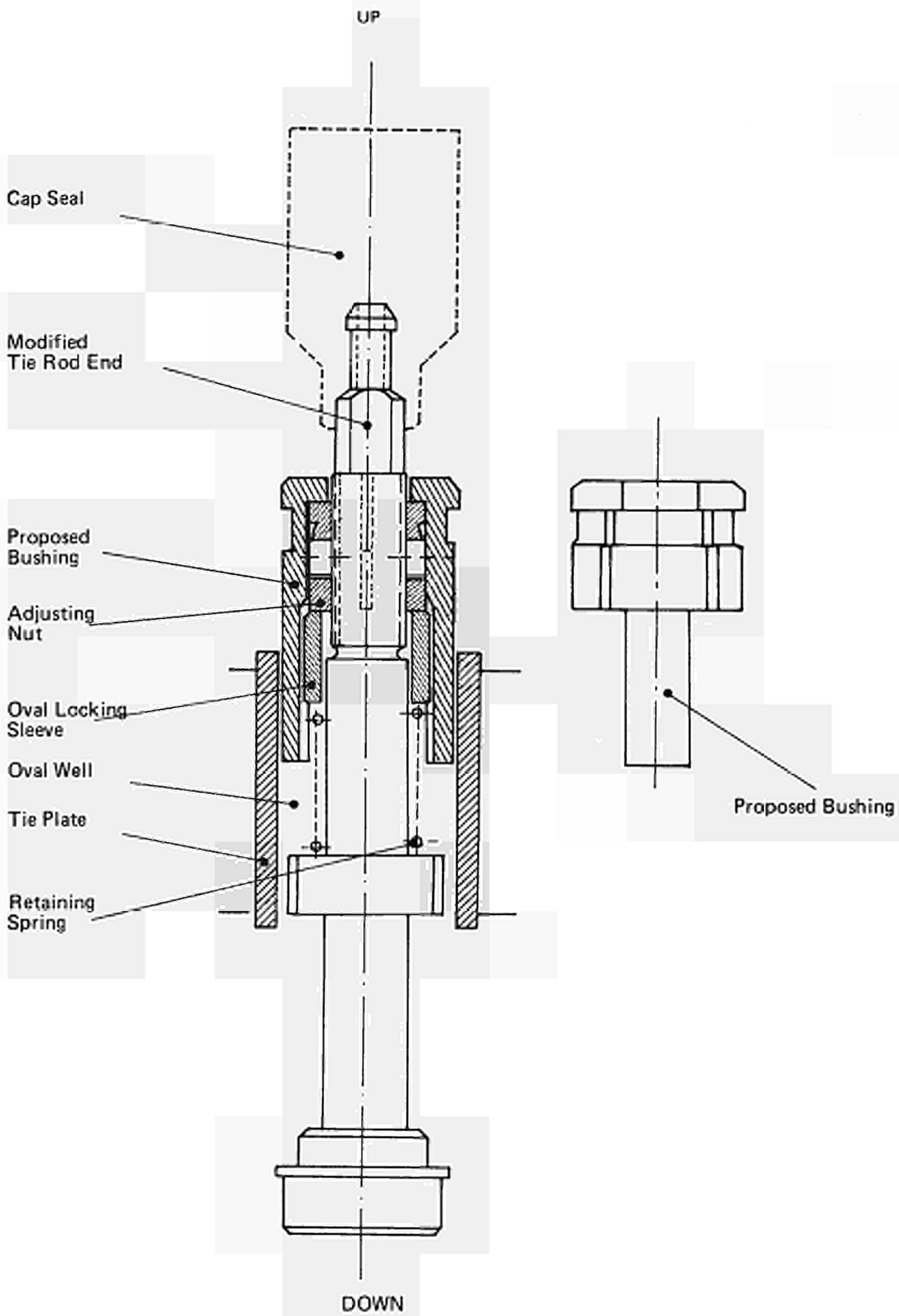

FIG 1 GENERAL VIEW OF THE LOCKING DEVICE OF THE UPPER END CAP TIE ROD

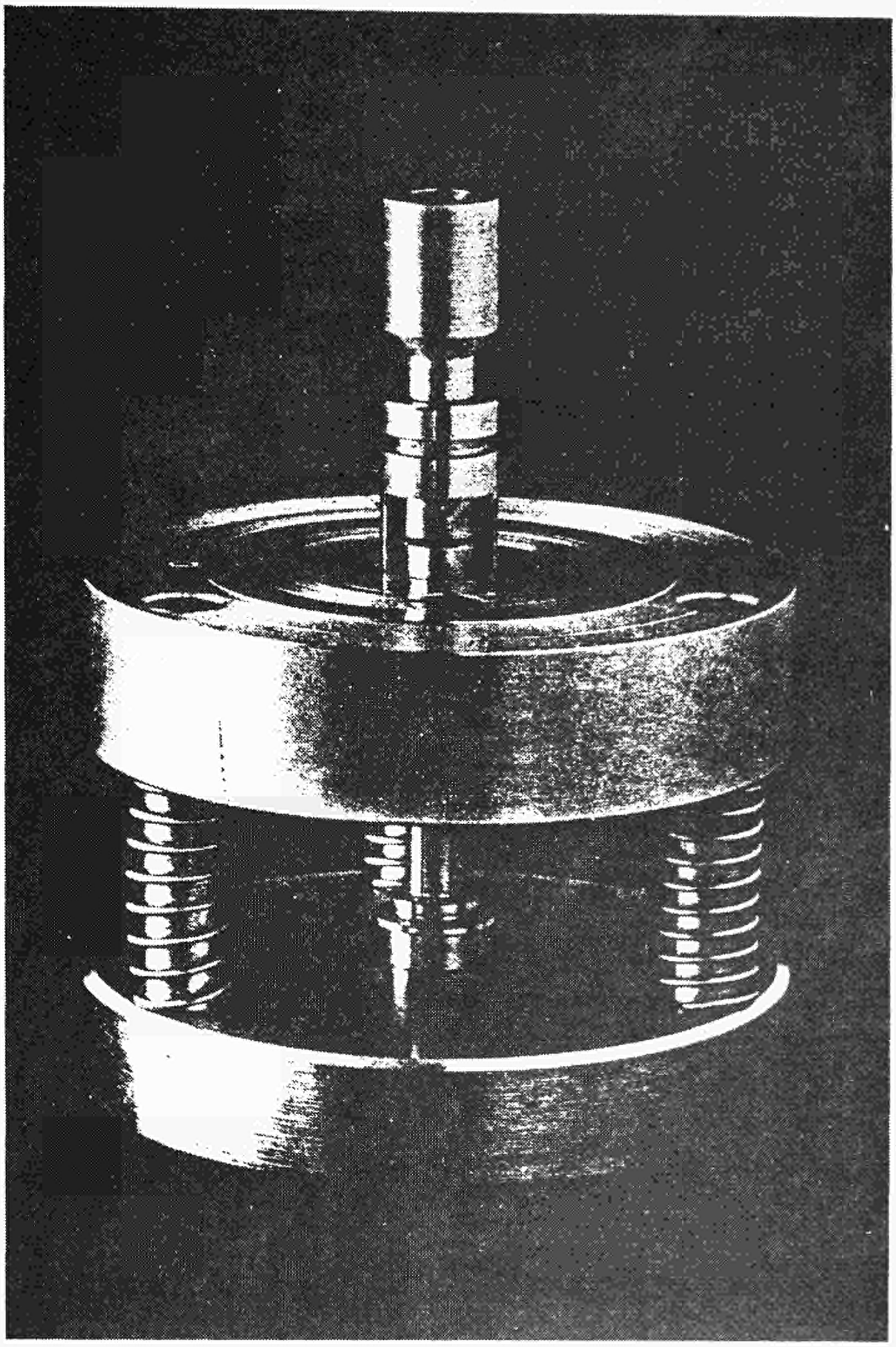

FIG 2 Photograph of the Ispra-made mockup showing the seal, the bushing (1rst version), the adjusting nut (in between the legs of the bushing) and the oval sleeve (just below the adjusting nut). The upper disk simulates roughly the upper tie-plate.

(Remark : This illustration has been reproduced from the best original available).

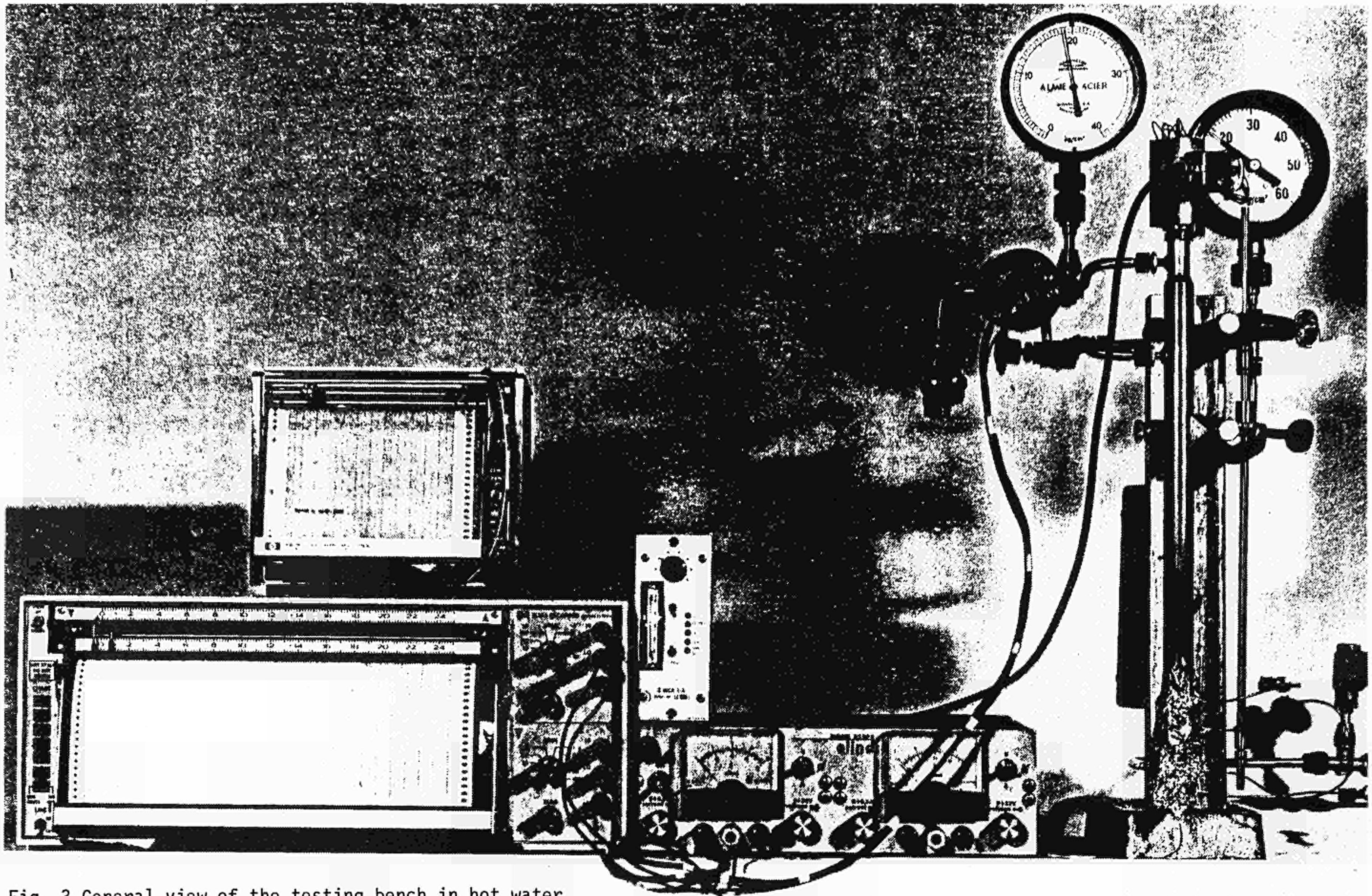

Fig. 3 General view of the testing bench in hot water

(This illustration has been reproduced from the best original available).

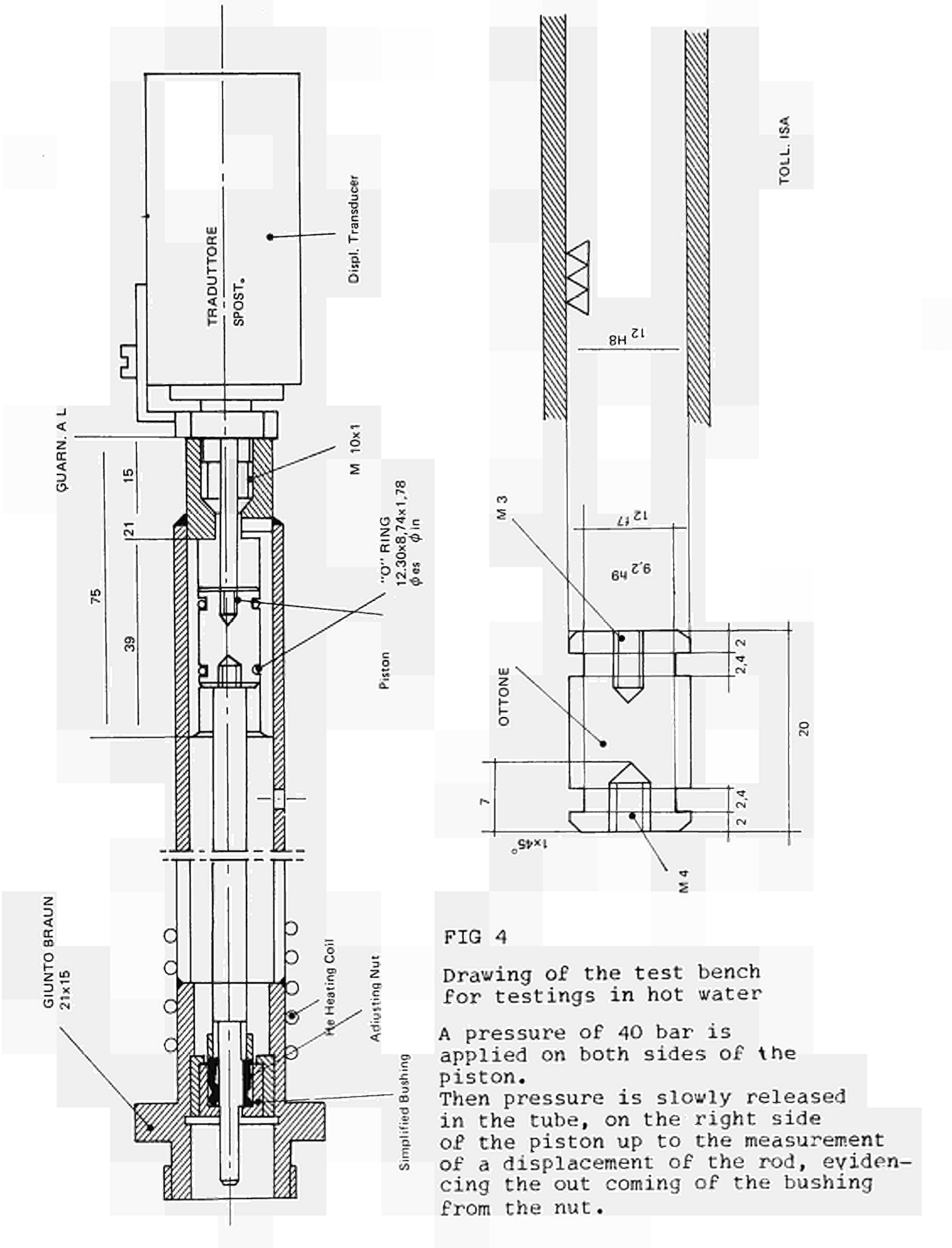

FIG 4

Drawing of the test bench
for testings in hot water

A pressure of 40 bar is applied on both sides of the piston.
Then pressure is slowly released in the tube, on the right side of the piston up to the measurement of a displacement of the rod, evidencing the out coming of the bushing from the nut.

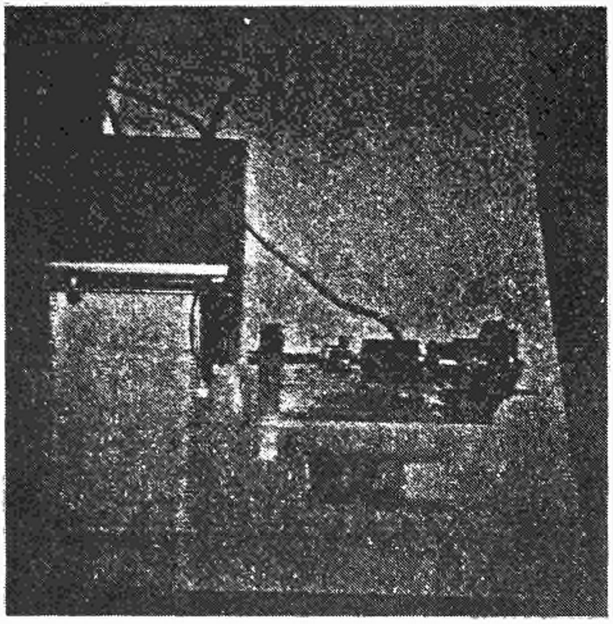

FIG 5 View of the simplified bench used for measuring the friction force between Bushing and Adjusting Nut

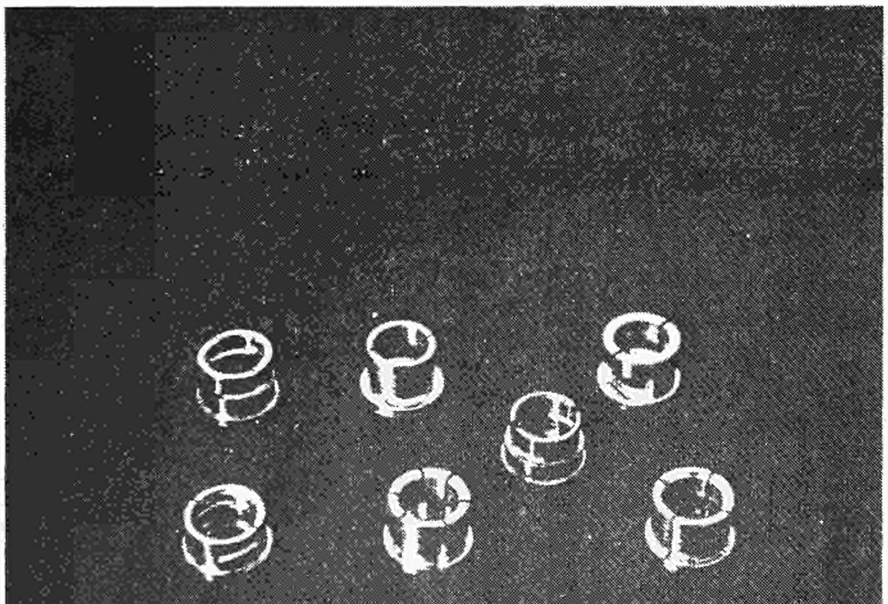

Fig 6 Simplified Bushings (no legs) as for the screening tests.
The lower on the right side is the selected "Second Version"

(Remark : These illustrations have been reproduced from the best best original available)

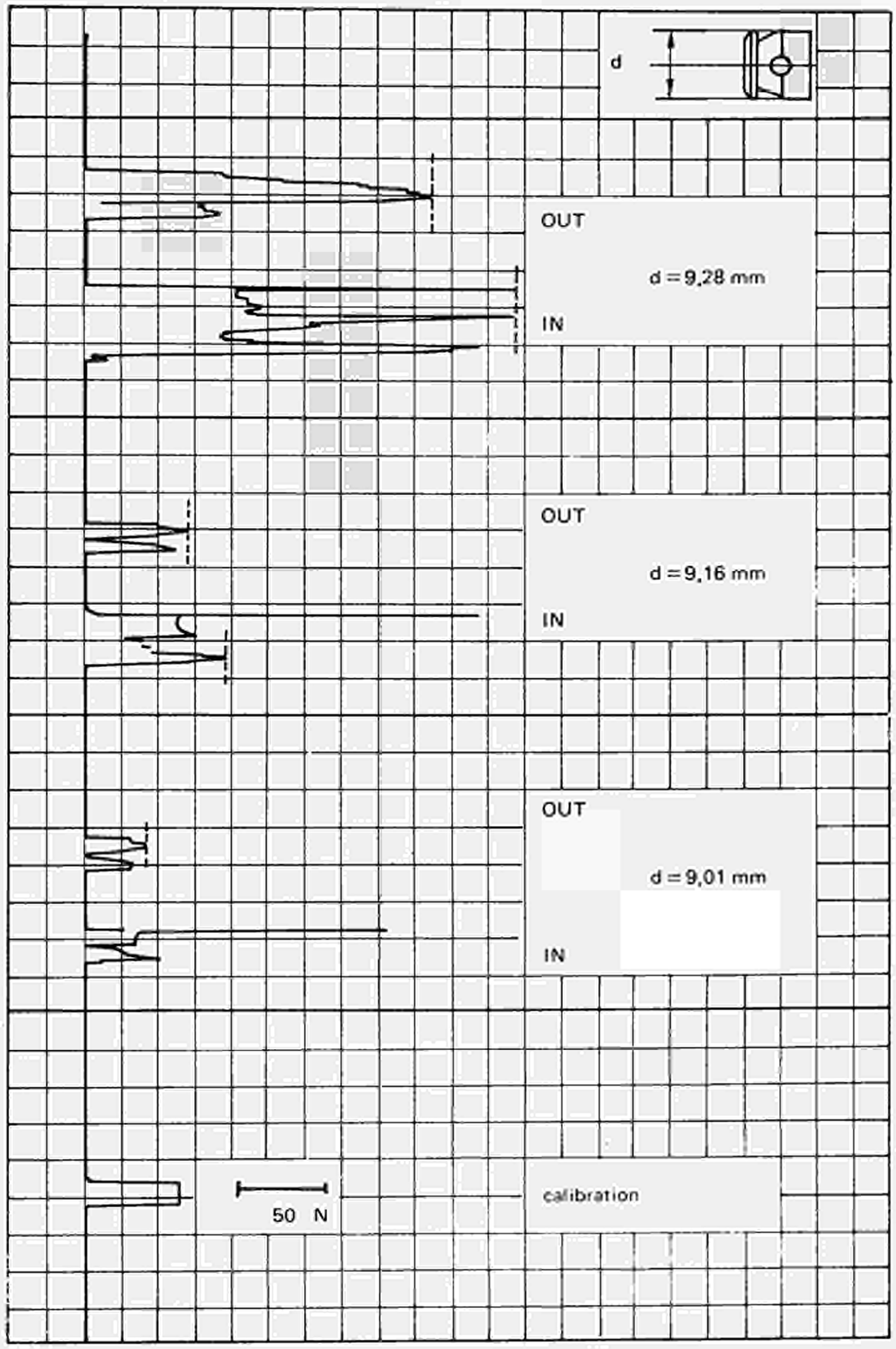

FIG 7 Example of Friction Force Measurements obtained between the Bushing(second version) and three calibrated Nuts:
d min, d nom, d max

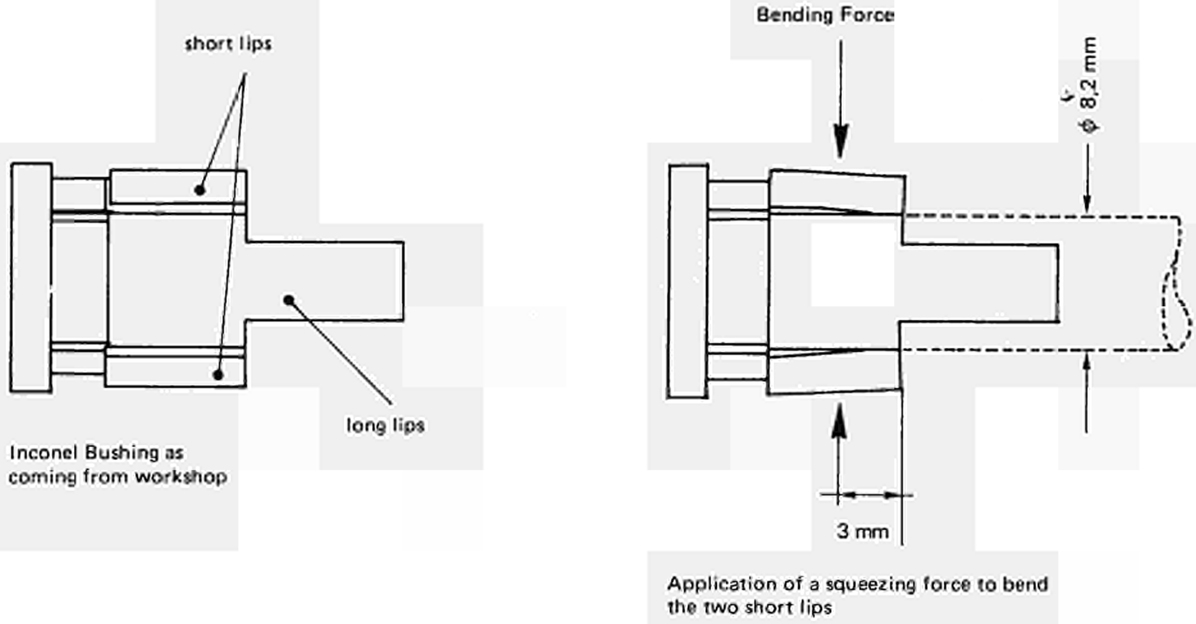

FIG 8 Sketch showing the bending of the short lips as applied to the bushing prior to make the heat treatment.

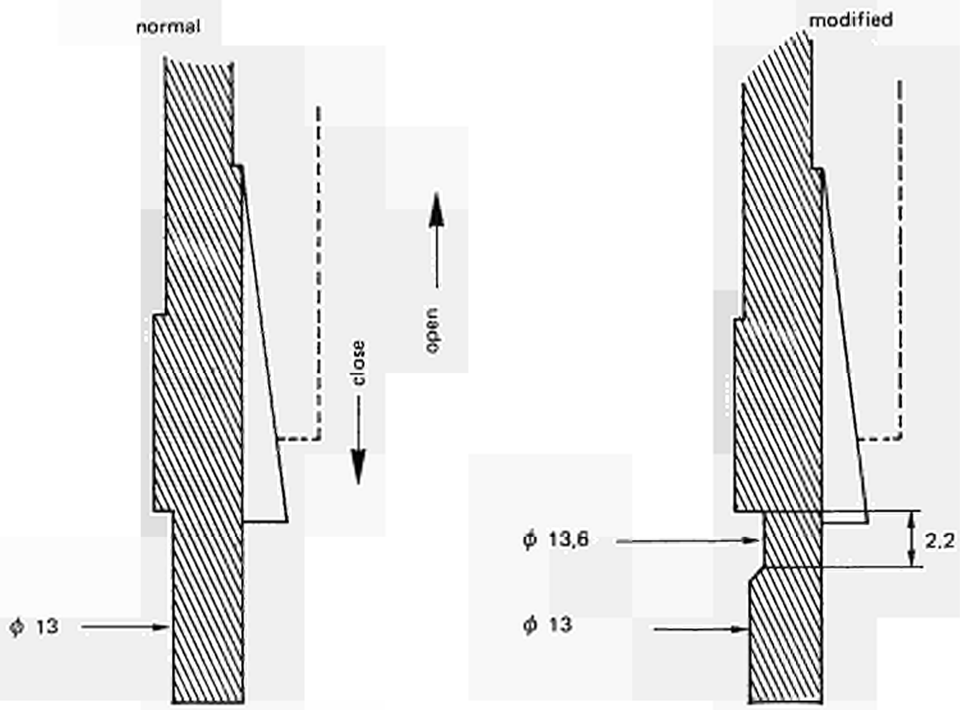

FIG 9 Sketch showing the modification of the handling tool in Kahl, to make it capable of putting in and pulling out the bushings

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1	275007669		162.2	86		037	88	<001	1653	<01	697	22				<002	29	243						7274		

TENSILE TEST AT ROOM TEMPERATURE

	ULTIMATE	1% YIELD	0.2% YIELD	% ELONG IN	% RA
	MPA		MPA	4DIN	
1	1269		883	250	430

TENSILE TEST AT ELEVATED TEMPERATURE

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	ANNEALED HARDNESS	AGED HARDNESS	GRAIN SIZE
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Charge-Nr.:	mit Attest				
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[redacted]	ø 16 mm	5		8.900	
2491 X	ø 19 mm	5		13.000	
				1 Bund	33.–

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Venice, Italy, 14-18 May 1984

RECENT PROGRESS IN THE FUEL ASSEMBLY SEALING PROCESS DEVELOPED AT JRC-ISPRA (VAK III) AND RESULTS OBTAINED DURING THE LAST DEMONSTRATION AT THE KAHL EXPERIMENTAL NUCLEAR POWER STATION

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Abstract

During the year 1983, a particular effort has been devoted by the JRC-Ispra to improve definitively the VAK Seal and the related sealing technique. A new version has been studied which embodies a stronger marking process for the seal's identification and a breakable grip to improve the integrity check, but keeps unchanged the external shape and the attachment feature to the fuel assembly. The results obtained for the last experiments in Kahl are presented in this paper.

1. Introduction

It is now well known that experiments are carried out periodically at the Kahl facility, in the Federal Republic of Germany, aimed at the assessment of the feasibility of sealing systems for safeguarding LWR Fuel Assemblies. This activity is part of the FRG Support Programme to the IAEA and its framework is the Task D3 and related Group. The performance of such experiments in realistic in-field conditions is made possible thanks to the opportunity offered by the Kahl facility (Versuchsatomkraftwerk) and the research and development of the sealing techniques are implemented by two different laboratories working presently on two possible solutions both using the ultrasonic principle. SANDIA National Laboratory, Albuquerque, USA, works on a solution with external marks to give an imprint to the seal, whereas ISPRA Joint Research Centre, Italy, is working with internal marks for the same purpose. Within the D3 Group other interests are represented which include electricity suppliers (VDEW, RWE), power station operators (VAK, RWE, BW), some potential seals manufacturers (NUKEM) and fuel producers (KWU, EXXON) and of course the International Atomic Energy Agency. The activity of this group, along with its composition has been given several times in the past[1,2] and what is being presented in this contribution mainly deals with the progresses accomplished since 1982 with the sealing technique developed at Ispra and with the seal called VAK III.

This work is due to a desire not to stop the development of an ultrasonic sealing technique - based on the internal marking of the seals, even though discouraging results were obtained for what concerns the integrity check requirement, the signature repeatability and vulnerability tests outcome. The decision was also linked to the fact that many features, developed in connection with the seals, had proven to work correctly and these appeared to be as important as the seal itself in the sealing procedure. Such features include handling tools, locking configuration, materials suitable for the seals fabrication, brazing skill, ultrasonic instruments, etc.

On the points related to these difficulties, it was decided to review the concepts which were kept unchanged until 1982, i.e. stationary reading and integrity check through an internal check of the tierod end (never implemented). Thus we were led to reshape the solution while keeping as much as possible of what had been imposed by the past and found to function correctly. A tentative experiment to use mechanically obtained external markings as a means to get stronger marks was shortly abandoned at the prototype level because no sufficient protection against forgery could be displayed. It was soon followed by the so-called internal external marking process (MEI: after the French words: Marquage Externe Interne), which means that solid elements are first worked with mechanical tools and then incorporated into a body which in turn is closed with a plug, the whole structure being then brazed in an inhomogeneous and random manner. This process leads to an effective internal marking provided with stronger defects, or cavities (whole magnitude is unpredictable) and difficult to tamper with. These kind of marks also require that the transducer is moved with respect to the seal body so that the inside of the seal can be "read" and as much as possible of the cavities reviewed by the focalized transducer.

2. Background on the Basic Requirements

Numerous attempts have been made in the past years to define in an exhaustive way the criteria and requirements for the production of seals and sealing systems[3]. Nevertheless it can be useful to make some comments on the basic requirements in the light of the experience gained so far.

According to the general concept, a cap-seal is aimed at the prevention of any possible dismounting of a fuel assembly, following the normal disassembling procedure. Thus it seems natural that some of the nuts which are screwed on top of the assembly and keep the bundle tight with the upper grid, be made impossible to withdraw or that the locking device they command be made impossible to operate, by means of seal capable of blocking their function as long as it remains unchanged or unbroken. Fig.1 shows schematically two such situations.

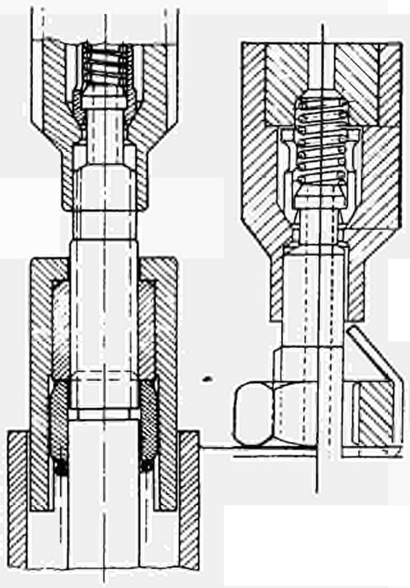


Fig.1 - VAK II and VAK I solutions.

The seal must be clamped on the structure which is generally (but not necessarily) obtained by means of elastic jaws able to grip a grooved extension.

The grip can belong to the seal, as in the Ispra solution, or to the structure, as in the Sandia solution[6] (FAID), Fig.2. Breaking or extracting the seal actually means breaking some part - or some parts - of the griping device so that it results in a change detectable by the inspector while an integrity check is performed.

The most important feature of a seal is its ability to be identified with as little risk as possible of stating wrongly whether it is the same as in a previous check, or not. Such an authentication is frequently called identity

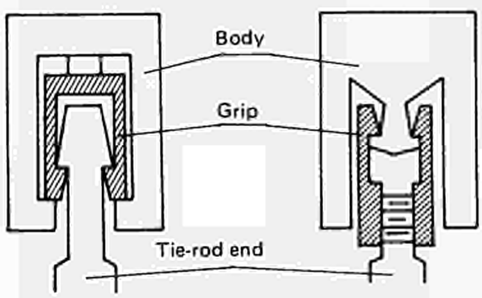


Fig.2 - Two locking configurations.

check and is presently considered as possible only through a reasonably stable marking of the seal to be read by a reasonably stable technique, capable of displaying faithful images of the marks embodied into - or in - the seal. The difficulty is that further to the requirement of having stable and strong marks, there is a requisite that these marks, which generate the signature of the seal, be made randomly, which means in an unpredictable arrangement, so that it becomes reasonably impossible to copy them.

Provided that the signatures are good, that is easy to recognize on a chart, another problem is raised when they must be automatically identified. Basically, it is not essential to rely on an automatic check to decide on the identity of a particular seal under inspection. Because an inspector could accept to compare two images - or two graphs - while performing a check, provided the signatures are not too complex as for the cheques at the bank. But we know computerization is in vogue and it offers the possibility to record and process the data given during an inspection. Yet, it is not evident that the pattern recognition methods at present surpass the human eye capabilities. It could be a sound proposal to rely on both automatic comparison and inspector judgement prior to pronouncing an identification decision. Nevertheless, because of the nature of the signals delivered by the ultrasonic methods, it is possible to apply correlation computation techniques to the random - or pseudo random - y(t) functions they give. Our own experience tells us that, generally speaking, as long as our eye is satisfied in comparing two curves which appear to be practically superimposable, the further computation performed on the values given by these curves leads to a high coefficient of correlation. Conversely, when sight presents (and also our brain) difficulties in finding similtudes, it means that the signals are too rich or too long, or too different one with respect to the other. In fact, as the richness of the signals increases, the relative amplitude of the fluctuations decreases and, by turn, also the precision of the comparison. This comes from the very fact that the possibility of including detectable defects into a matrix or a support is limited inside a determined amount of space. Thus, the evaluation of the automatic capability should start after a good repeatability has been obtained considering the output curves given by the experiments.

The vulnerability of the seal is also an important aspect to consider and the mechanical concept has to be designed in order to avoid that the seal could be extracted - or tampered with - without the knowledge of the inspection people.

There are other requirements which are important in sealing systems, like the reliability and good functioning of the handling tools, their easiness to operate, the seals dimensions, the materials they are made of, the ultrasonic equipment, the stability of the transducers and marks with respect to temperature changes, etc. These problems, apart from the question of the temperature influence, were solved in the previous version of the JRC Seal (VAK I and VAK II). The difficulties concerning the influence of the temperature have been solved with the modification of the markings.

3. Improvements since 1982

After the decision of the D3 Group during its 10th meeting in October 1982 not to introduce Ispra seals with external markings[4], nor any other VAK II seals, because of their scarce reproducibility during the October 81 Campaign in Kahl, it was decided at Ispra to try to fulfill the requirements not already met, within the next possible campaign in October 1983. The improvements which were obtained cover the following points.

3.1 Identification

Markings. It was decided to built strong marks inside the seal's body, using a stable of small disks placed one upon the other, all of the same diameter, but of various thicknesses, each provided with one or two radial slot, cut in any possible position. The disks were typically 10 mm o.d., about 1 mm thick with slots wide about 1.5 mm. The cavities in the seal were obtained by piling up the disks into the internal upper room of the seal, in an undetermined manner, so that, after putting an established amount of brazing powder (Wall Colmonoy Nicrobraze 10) and plugging a tighting screw, with the effect of pressing the pile, the whole was heated at 1000°C and brazed. The result, thanks to an adequate command of the brazing process, results in a partial and unpredictable filling of the slots, whose positions are also unknown (Fig.3).

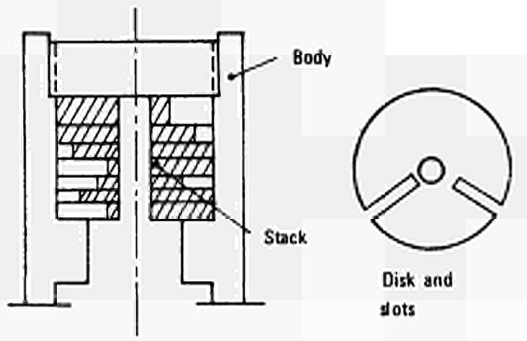


Fig.3 - Arrangement of the markings before brazing is applied.

Thus a cylindrical volume, about 10 mm o.d. and 8 mm in height could be obtained with built-in randomly distributed cavities, all having a portion of their surface, perpendicular to the axis of the cylinder. This is the basis of the new VAK III seal and explains, as mentioned above, the "MEI" initials. These detectable marks obviously called for the use of a scanning technique, and due to the limited possibilities to increase the seal's height and the impossibility to increase its diameter of 13 mm, it was decided to work with a radius of 3 mm for the revolution of the transducer with respect to the seal.

Identity tool. Along with the development of the markings, and taking into account that we would have to continue using the ultrasonic equipments currently in use at Ispra, we decided to develop a rotating transducer holder capable of mounting calibrated Aerotech 10 MHz focused transducers which we had at our disposal (in a limited number). The specific requirements we added were:

- to fit on the seals, as did the previous identity tool with a static transducer;
- to be easily extendable, from the laboratory size (0.5 m) up to the in-field size (6 m), by adding intermediate elements between the lower part, where the transducer is located, and the upper part, i.e. the driving motor;
- to be transportable;
- to keep a constant speed in all possible configurations.

A solution was found using friction synthetic blades to guide the transducer holder in rotation, owing to the difficulty of installing ball or journal bearings as available on the market. The transmission of the movement was obtained by means of a central shaft terminated at the lower extremity by a coupling bellows having the effect of eliminating transversal thrust on the rotating elements while using the tool in its long arrangement, as in the reactor pool. Tests showed that the rotation remained regular (about 1 rev in 10 sec) when the tool was lengthened and the assemblage or dismounting operations were found to be easy. Fig.4 is a photograph of the tool in its short configuration with no prolonger inserted.

Temperature testings. At first, the identities of the seals were tested on an old bench consisting of a vessel full of water, in the middle of which a mandrel was rotating in front of a stationary transducer. The seal under test was fixed onto the mandrel. With this situation, converse from the one in the new tool (where the seal is steady and the transducer rotates around it), led to promising results which were confirmed when the new tool was implemented. Curves as in Fig.5 were obtained when the temperature was varying from 22 to 32 and 42°C. We wanted not to exceed 50°C in order to avoid damaging the few transducers we had. It became clear that the very nature of the new marks and the fact that we were working with lower gains contributed to reduce considerably the sensitivity to the temperature change.

In addition, some seals were also subjected to thermal shocks with an amplitude of 300°C with no change detectable in the signature.

3.2 Integrity

Breakable grip. In the VAK I seals, the idea was to introduce a very small transducer in a central hole, drilled in the seal and to go further, like with an endoscope, up to entering the central channel of the tie-rod extension and inspecting it in the zone where it would have normally broken if the seal had been extracted. Considering the difficulty to complete such a technique, a second idea was to arrange the seal gripping device so that an element inside the seal would be broken prior to the tie-rod itself and by a lesser force than the one required for breaking the tie-rod and extracting the seal. Whereas the grip inside the seal was free to move, according to the previous designs, it was connected to the identity upper part of the seal in the new version. The connection being a kind of stud passing through

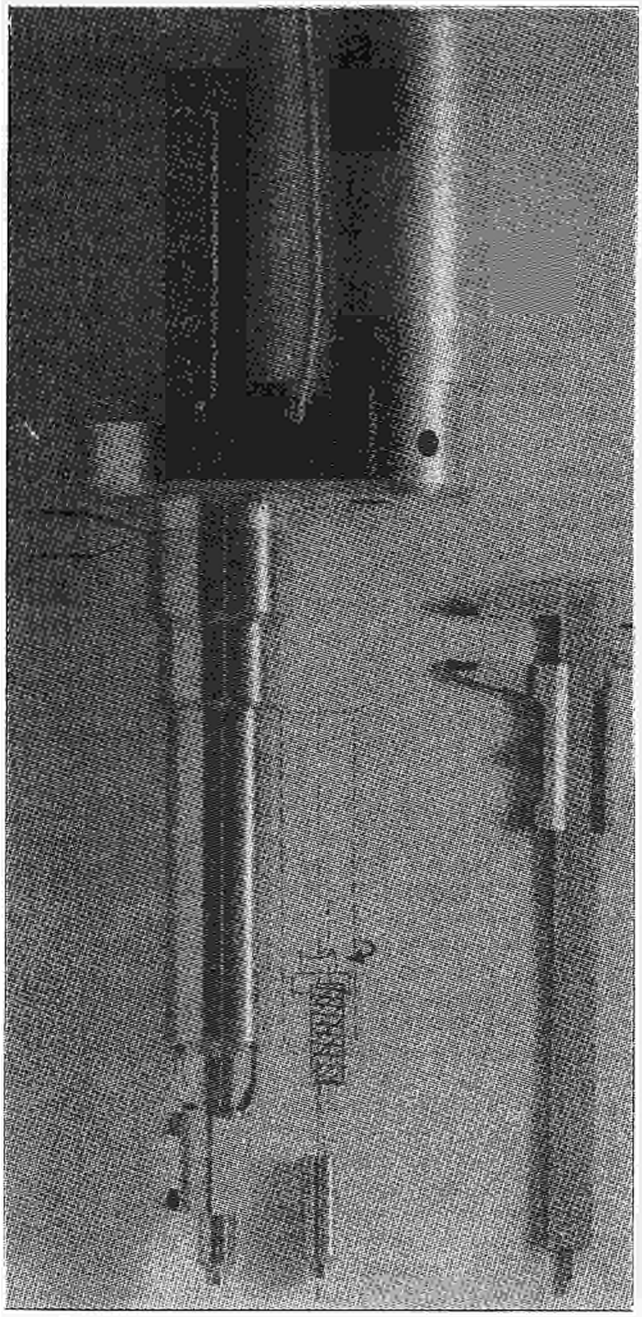


Fig.4 - The new identity tool with no prolongers. The transducer holder extension is seen fitting to a seal.

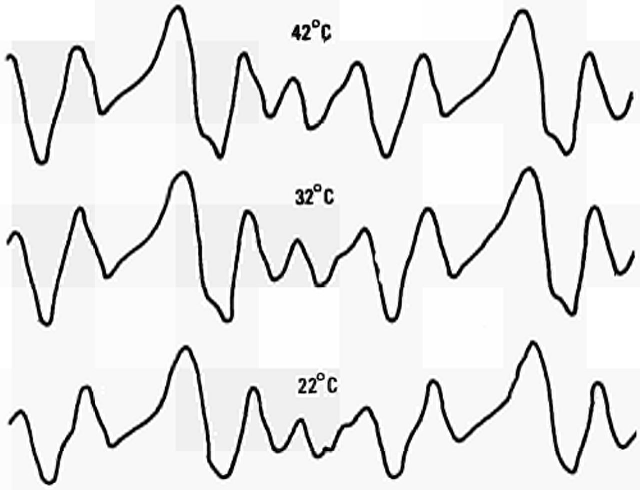


Fig.5 - Three identity curves of the same seal at 3 different temperatures.

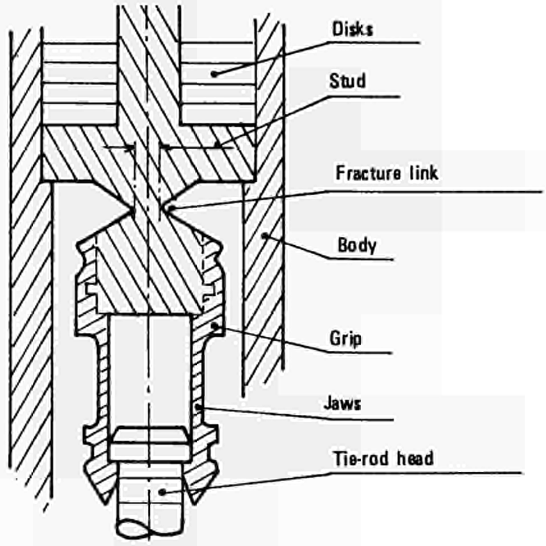


Fig.6 - Arrangement for connecting the grip to the upper part of the seal.

the identity disks stack (where a central hole was previously machined) and embedded into it by the brazing process. The lower part of the stud projects from the identity zone and is shaped with a weakened section followed by a thread on which the grip (built with the same material and dimensions as the ones in the previous solutions) is screwed tight (Fig.6). The stud is an excellent wave-guide and its lower end is flat and reflects the ultrasounds like a mirror. When the seal is pulled for extraction, the stud breaks and its bottom end does not give any echo on the reflectogramme (Fig.7). After the extraction has been performed, the two broken parts, i.e. the grip and the tie-rod end continue being clamped together and no part is left on the fuel assembly side. Furthermore, it will be seen below that the grip's jaws cannot be re-opened as a special feature is provided to protect the access to the grip.

<u>Integrity and breaking tools.</u> The handling tool for taking the identity signal, already in use in the Kahl reactor and built years ago for the identification of VAK I and VAK II seals, was to be used for the <u>integrity checks</u> of the new seal, as it was designed to work with a central steady transducer. The tool for extracting the seal (breaking tool) was also to be re-used at Kahl. Only slight modifications were made on both tools to adapt to a longer seal (42 mm in lieu of 33 mm).

3.3 <u>Vulnerability and locking mechanism</u>

<u>Vulnerability.</u> Tests performed in 1982 by J. Wepner, from EKS Germany, showed that VAK I seals were insufficiently safe, because it was possible, after extracting the seal, to re-open the grip's jaws, eliminate the broken tie-rod end and re-use the seal without changing either

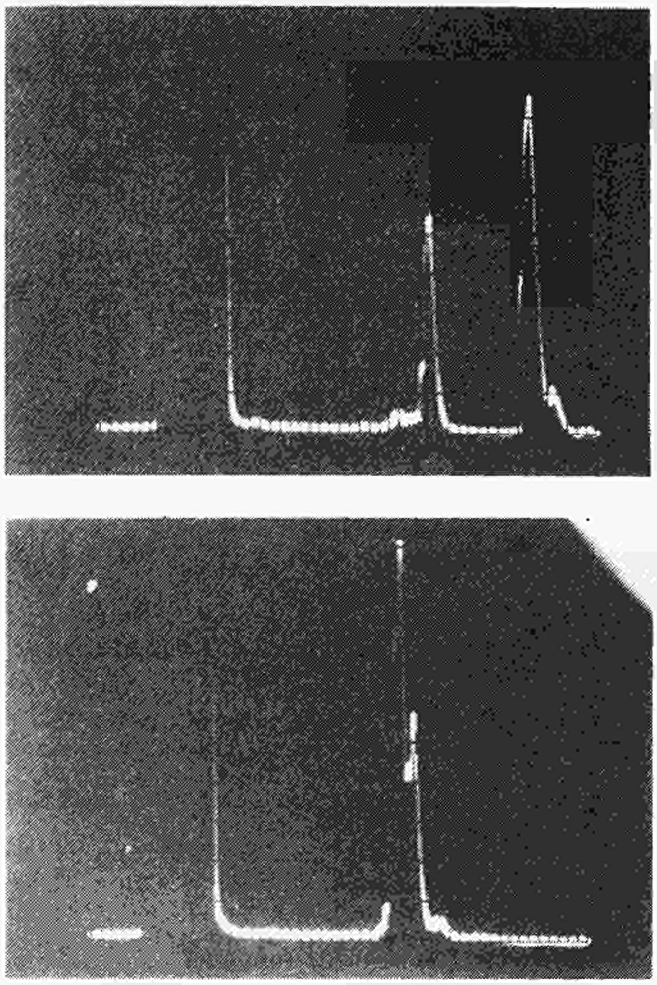


Fig.7 - Echograms before breaking the fracture link (above) and after breaking the fracture link (below).

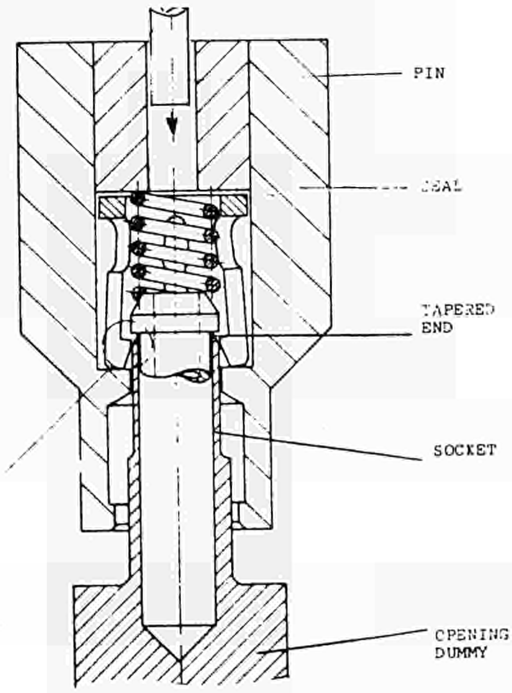


Fig.8 - Vulnerability tests.

its identity, or its integrity (which in any case was not possible to check). See Fig.8. This possibility to open the grid was helped by the use of a pin to be slid into the central hole of the seal. In the VAK III version, this central hole was eliminated because the integrity check was to be related to the inside of the seal and no more to the tie-rod end. Nevertheless, the revision of the grip and the fact that breaking its stud would have required a certain downstroke to allow the separation to be completed, led to the design of an arrangement which keeps the tie-rod head secured in the grip and makes it impossible to re-open the jaws as described below.

Locking design. The arrangement, after various tests to assess the capability of the parts to withstand the breaking thrust and to function properly, has been embodied as on Fig.9 which gives the general configuration of the seal as it is clamped on the tie-rod end. The achievement is mainly characterized by the position of the spring around the grip, the presence of a sliding cup, transmitting the spring thrust to the tie-rod end, and the presence of a clip-ring aimed at locking the grip's jaws once they have seized the tie-rod head. The materials employed are stainless steel 304L and Inconel X750 as in the previous seals. The kinematics of the locking operation is illustrated in eight phases in Fig.10.

3.4 Output signals and processing

The ultrasonic equipment which has been in use for many years was kept. It consists of the well known and frequently illustrated FTS Mark 1 Sonic Instrument whose reliability has been tested for long periods. The transducers used for the identification and for the integrity checks were of the same type. Focused 10 MHz 0.25" - "Aerotech" transducers with a 2" focal distance in water.

Integrity signals. The procedure was practically the same as for the identification of previous VAK II seals. Echograms given on the oscilloscope window of the Sonic Instrument were photographed and pictures as on Fig.7 were taken. Owing to the simplicity of the echo, the evidence provided is clear enough to decide whether the seal has been broken or not. No digitization of the signal seemed necessary at that stage of the study.

Identity signals. Conversely, the technique of taking pictures has been abandoned for the identification of the seal, because the echo itself is changing as the transducer is scanned in front of the seal. The output voltage given by the Sonic Instrument is proportional to the amplitude of the higher peak seen on the oscilloscope at a certain time. This means that any azimuthal position of transducer with respect to the steady seal corresponds to a specific situation giving an echogram. With the rotation the echo changes as defects are passing through the transducer's field-of-view. The fluctuations of the maximum amplitude M(t) with time gives a curve whose pattern represents the identity signal. As the defects in the seal body are larger

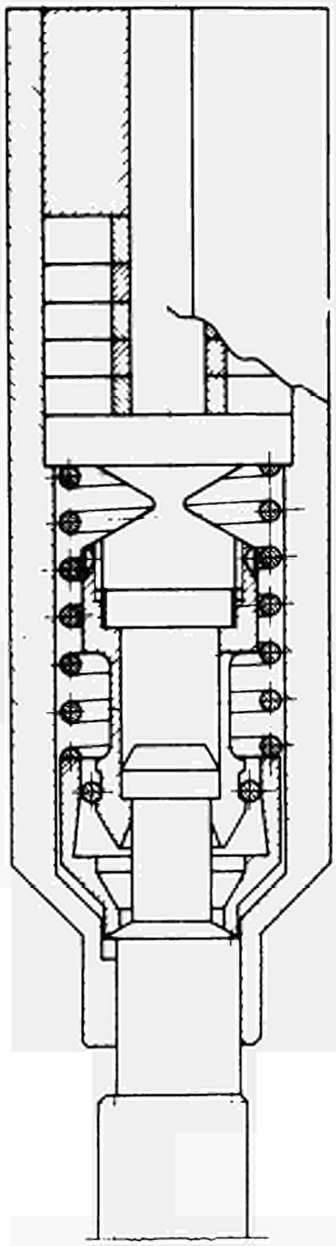


Fig.9 - VAK III MEI seal clamped on an Exxon tie-rod end.

- and provided with a better reflectivity - than in the VAK II solution, and because of the use of focused transducers, it was possible to work with a gain level of about 50 dB. Curves as in Fig.5 were obtained after a usual double revolution. Fig.11 schematically shows the correspondence between the echogram and the identity curve. Normally, during the preliminary tests performed on the first batches of seals, the identity curves were recorded on t,y chart recorders, and the comparisons were made on the graphs. Later on the signals were memorized on cassette recorders or digitized and processed with a HP 9825 A desk computer.

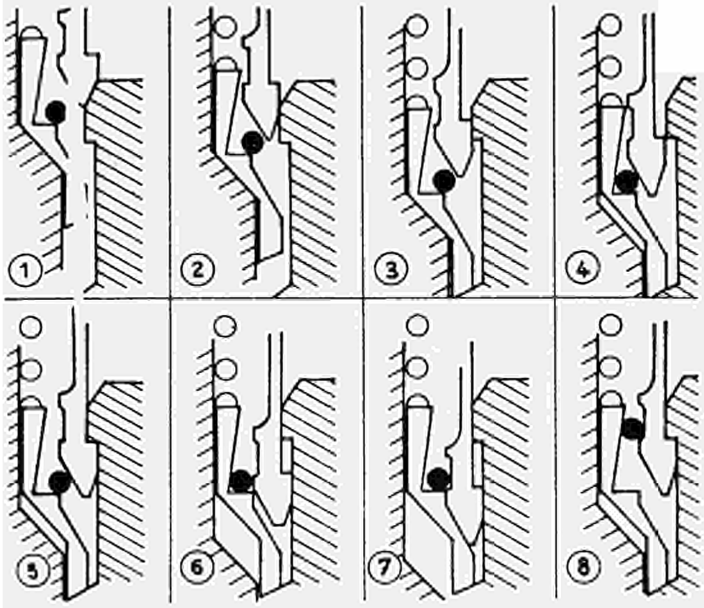


Fig.10 - Phases of the clamping of the seal onto the tie-rod end.

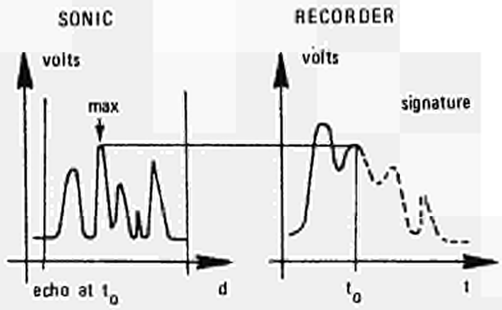


Fig.11 - Correspondence between echo and identity curve.

Comparison of the signals. The output of the Sonic Instrument was normally 0-2.5 V. No additional amplifier was used. This analog signal was acquired by a digital voltmeter HP 9872 (peripheral, to the desk computer). It was sent in parallel to an analog Philips cassette recorder as illustrated in Fig.12. Thus, the signal could be recorded in either way: on an analog cassette the digital cassette memory of the computer. Furthermore the signal could be visualized both on the chart recorder (HP 680M) and on the plotter, peripheral to the computer (HP 9872A). The current procedure, in the laboratory, was to take a signal to the computer and to check it on the chart recorder or vice-versa.

Any identity was converted into a series of values. For instance: 300 points which appeared to be a reasonable number. The series were simply compared by difference or by correlation computation and the method is described elsewhere[5]. Graphs as in Fig.13 were given by the computer. They were systematically used for comparing two signatures automatically. As the start of the rotation of the transducer during the taking of an identity could have been delayed or anticipated, it was necessary to shift one curve with respect to the other. Generally an amount of

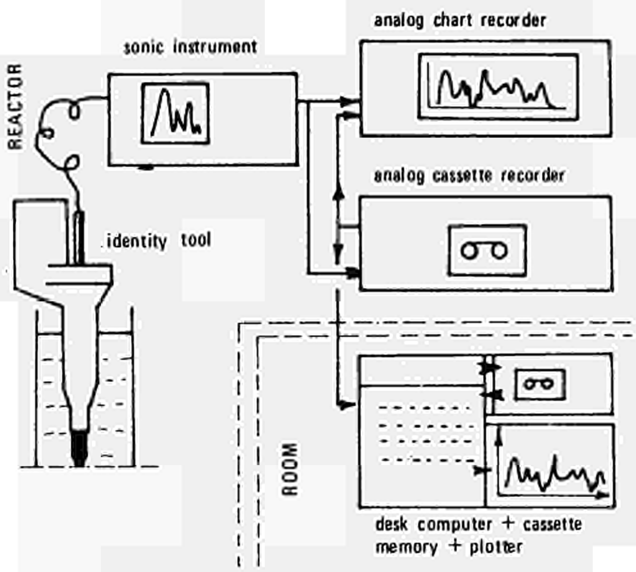


Fig.12 – Block-diagram of instruments.

± 1.7% was sufficient to obtain the maximum of the coefficient of correlation between two curves given by the same seal. The coefficient R from curves of different origin was also calculated 10 times, within the shift range of ± 5 readings.

The seals for Kahl were measured in a laboratory experiment called "Phase 0". The "auto" and "cross" correlations were performed, simply applying the Bravais-Pearson formula. No particular processing was necessary with the reading values. Graphically the curves were almost superimposable when produced by the same seals. In that phase 0, the "autocorrelation" coefficients were all equal to or above 0.990. The "crosscorrelation" coefficients were ranging from -0.17 to +0.53, the second highest value being 0.34.

These tests indicate that the comparison means used as a basis for a future automatic check are suitable and fulfilling the requirement. It was decided to use the same equipment for the Kahl experiment in October 1983. The program used for calculation was simple though it was not optimized at that time.

4. Kahl Demonstration

The demonstration in Kahl was performed on November 3 and 4. The necessary equipment was transported by car from Ispra. The seals, the new identity tool, some parts to modify the existing tools in Kahl, the equipment as described above, plus a Polaroid Camera and a special amplifier to perform a breaking force measurement. The fac-simile in Fig.14 summarizes all the operations we were required to perform. It also indicates the tools which were used.

All the operations were performed successfully even though they happened in a different order. Operation No.7 led to the expected results. One seal (nb 5) was broken in two stages. The breakage of the integrity stud occurred with a traction force of 1350 N and the second breakage at a level of 2700 N.

No mechanical problem has been encountered. Apart from a slight re-opening of the extraction tool, just after the breakage of a seal. The identity tool in its long version has proven to work properly. Some very limited mechanical noise being added by the "long" transmission.

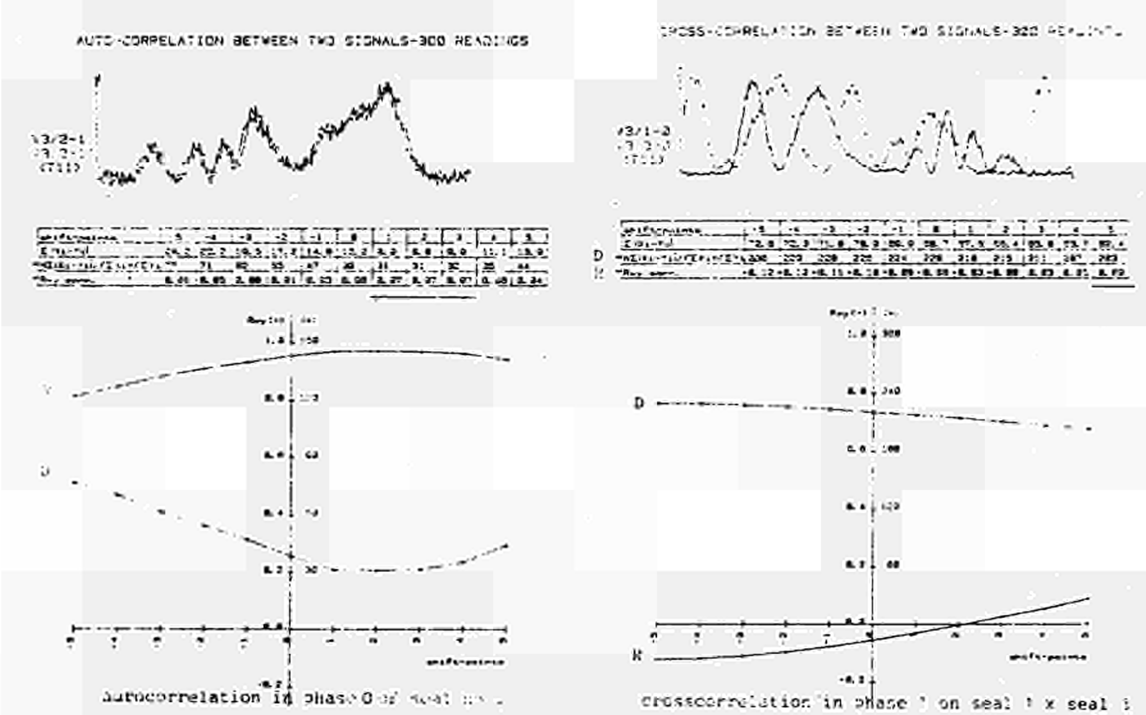
When repeating an identification, finding exactly the same starting point was not easy, as we expected. The system triggering was based, in that version, on both a mechanical relocation of the tool with respect to the seal on the fuel assembly and a cam-switch contact to start the recording process. Nevertheless the shifting of a signal with respect to a second one was compensated by the "shift programme" in the computer.

Operation No.14 was planned to be completed in a separate room, just after the previous operations were terminated in the pool room. The data acquired in the reactor ("Phase 1") on the cassette-recorder were then computerized to give the "autocorrelation" and "crosscorrelation" curves and coefficients both for the Phase 1 x Phase 1 comparisons and for the Phase 1 x Phase 0 comparisons. The last one corresponding to the higher difficulty.

The "auto" coefficients were found to be equal to or higher than 0.960 in the Ph1 x Ph1 comparison and equal to or higher than 0.930 in the Ph1 x Ph0 comparison. The "cross" coefficients ranged from -0.17 up to 0.71. The second highest value being 0.44.

After the demonstration, it was considered by the D3 group that the basic requirements had been fulfilled by this new seal. Further requests were then added. Ispra has worked on them and solutions are ready for the next May campaign, in a few days after the present conference. They were:

- make a shorter seal. The next one will be 37 mm long in place of 42 mm;
- incorporate a larger mark in the seal, to trigger the signal electronically. A solution has been found where the detection of this bigger mark starts the recording process without being taken into account for the correlation computation. This will be embodied in the May demonstration. For the safety an electromagnetic external trigger is also prepared and installed on the identification tool;
- modifying the grip of the extracting tool to avoid any re-opening after the breakage. The grip (nipple) has been modified according to the introduction of a flat surface at the bottom of the seal;
- improve – as far as possible – the detection of the fracture while performing an extraction. A further improvement has been obtained reshaping the grip stud in the seal (Fig.7 gives such a result);
- make the seal and the sealing process adaptable to a "dry" measurement. The seal is now designed so that rubber o-rings can be used to "seal" a water chamber around the seal to be inspected. This will not be ready for the next May exercise;
- provide the D3 Group with laboratory results showing the dependence (if any) of the curves and the correlation coefficients on the temperature effects and the effect of changing the transducer. This is being prepared for the May campaign.



For each comparison, one curve is shifted 10 steps with respect to the other. Each time, the correlation coefficient (R) and the normalized difference (D) are calculated and plotted.

Fig. 13 - Examples of the method used to compare two signatures.

Sealing demonstration with VAK III Seals at Kahl, 3/4 November 1983

Aim:

Perform the demonstration program as defined by the D3 Group, using new VAK III seals provided with re-inforced *identification markings* and a new concept for the *integrity check*.

Tools for operation:

Four special handling tools are used:

Positioning tool: This tool is for placing the bushing and the seal on the extended tie-rod as for VAK II.

Identity tool: This new tool is for the identification of the VAK III Seals. It is provided with a special rotating device.

Integrity tool: This tool is the old identity tool which has been modified to check the *VAK III Seal integrity*.

Breaking tool: This tool is the old breaking tool which was modified to adapt to a longer seal (42 mm in place of 33 mm) and to allow to break first the *integrity link* and second the *tie-rod end*.

Summary of the planned operations:

1. Application of 2 seals, under water, on one fresh F.B.
2. Identification of same two seals. Paper and tape record of identities.
3. Re-identification of same two seals. Paper and tape record of identities.
4. Check of integrity on same two seals.
5. Breaking and breaking force measurement of the breakable grip on one seal.
6. Check of integrity after breakage of the breakable grip (1rst level).
7. Breaking and breaking force measurement of tie-rod (Seal extraction).
8. Visual inspection.
9. Correlation process using the tape (cassettes) recordings to be performed on computer in the conference room.
10. Placing two seals (and related bushings) on each of two fresh bundles, in the dry storage. (4 seals are placed).
11. Identifications on the two F.B. as in 2 (It means 4 identification).
12. Re-identifications on the two F.B. as in 3 (It means 4 re-identifications).
13. Check of integrities on the placed 4 seals.
14. Correlation process to be performed in the conference room.

Note on the procedure

The present demonstration is based on a non-integrated philosophy as the operations are presented as clearly as possible and separately one from the other.

Thus, even if a unique tool is conceivable for both identity and integrity checks, we have prefered the use of two separate and single handling tools.

For the recording of identities, a chart recorder is used, on site, to visualize the signature, as it comes from the rotating transducer holder. At the same time this signal is recorded on a conventional cassette recorder. Cassettes can be used later on together with a table computer (HP 3052 A) for the correlation demonstration. The visual comparison with the charts is also possible.

Transducers

A unique kind of transducer is used either for the integrity check or for the identification procedure.

AEROTEH - 10 MHz - 0.25"
Focal distance: 2" (Water)

Fig. 14 - Fac-simile of the programme of the experiments carried out at Kahl.

5. Conclusions

We have presented the efforts JRC-Ispra has put into the seal VAK III, which is a cap-seal to be used on LWR fuel assemblies like the ones produced by KWU or by Exxon. This effort was made possible within the D3 Task of the FRG Support Program to the IAEA and the in-field demonstrations could be prepared and realized only through a strong collaboration with the Kahl facility operators and taking into consideration the technical comments from the Electricity Authorities.

The sealing technique and the seal have been reshaped in the light of the previous experiences. The steady transducer has been abandoned and stronger markings have been successfully introduced in the seal body so that the concept of internal marks could be maintained. With respect to the previous solutions (VAK I and VAK II) decisive progress has been obtained at the laboratory level and demonstrated in-field conditions on the integrity check technique, on the identification technique, on the vulnerability and on the automatic check procedure and related data comparison and correlation methods.

Both the safeguarding possibilities and the reliability of the sealing technique have been improved with the VAK III MEI seal. There are indications that further requirements can be fulfilled as for the length, the dry-testing and the automatic processing of the data. This applies in particular to the adoption of low cost minicomputers for the simplification of the programmes.

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COMPARISON BETWEEN DIFFERENT SIGNATURES A PRACTICAL EXAMPLE OF A SIMPLE PROGRAMME USED FOR DIFFERENT KINDS OF SIGNATURES

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Abstract

A programme which has been used successfully for the digitization and further camparison of signatures is briefly described. It has been applied to the comparison of signals obtained either from ultrasonic measurements, or from surface topography readings. Examples of results are presented. Other mathematical operators are indicated, as complement of the coefficient of correlation.

1. Introduction

The identification of an object is possible whenever it is able to deliver a signature under certain circumstances. Theses circumstances are generally the ones of a physics experiment, in which a certain number of parameters must be fixed and an output variable is measured and recorded. For the indentification purposes, such experiments are assumed to be sufficiently repeatable. This means that two requirements are fulfilled. First: from one experiment to the other, the measured characteristic behaves in the same way. Second: the means used to measure the said characteristic and to deliver the signature (which is a representation of it) are stable. Such a characteristic is intended to be either a physical property or a behaviour under some external causes. Most of the difficulties encountered when assessing identification techniques come from the confusion between these two requirements.

Nevertheless, provided that the characteristic chosen for the identification process be stable and that the possible changes in the measuring means are controllable, a simple computation process can be applied to compare automatically two identity signals, or signatures.

2. Basic Considerations

Studies recently undertaken at J.R.C. Ispra are considering the use of the surface textures of objects as a means for their identification[1]. This characteristic offers the double advantage of being random by nature and stable with time. Furthermore, reliable and proven techniques are available. Thus the two above-mentioned requirements are fulfilled and the method provided can be used as a reference while studying the repeatability of identification experiments with utrasounds.

The use of internal marks was the basic idea in the VAK cap-seal. The characteristic to deliver the signature was not the marking itself - which is extremely stable - but its behaviour under ultrasonic impulses, which is not stable. Getting a "permanent" signature from such a structure, by means of a steady external transducer (emitting-receiving transducer) has proved to be very difficult, in particular because this characteristic is physically dependent upon temperature changes, in an unpredictable manner.

In the recently developed VAK III version, the steady transducer was replaced by a scanning focused transducer and the marks were reinforced[2]. In this new version, the characteristic responsible for delivering the signature is the fluctuation of the energy reflected to the transducer by the strongest defect, as this one is crossing through the transducer's field during its rotation with respect to the seal. (Fig. 1)

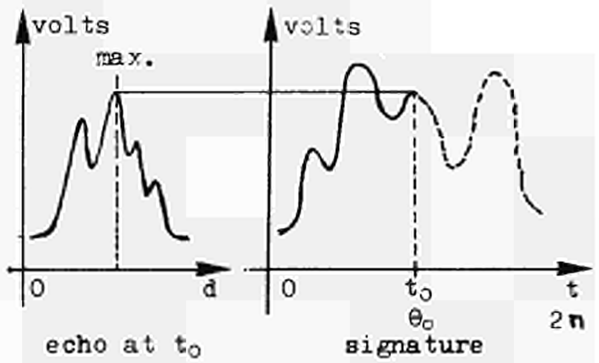
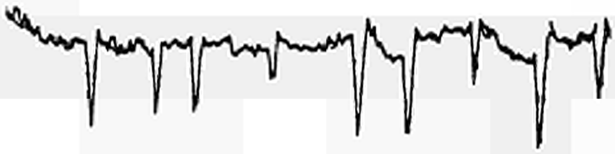


Fig.1 - Correspondance between echo and identity curve (signature)

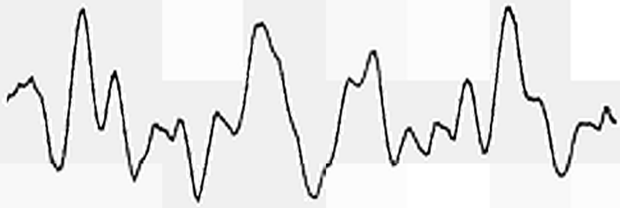
The improvement in the precision of the measurement also deals with the fact that the transducer is now exploring a far smaller volume at a time.

3. Signatures and paper recording

The signatures obtained from the surface measurements have a rather rich pattern. Depending on the technique used to finish the surfaces, the texture can be of different aspects (Fig. 2). Generally, the aspect is the one of a noise, when the surface is not marked afterward.



Grounded texture

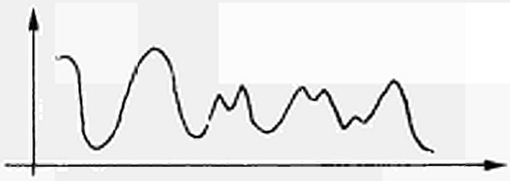


Sparkling-machined texture

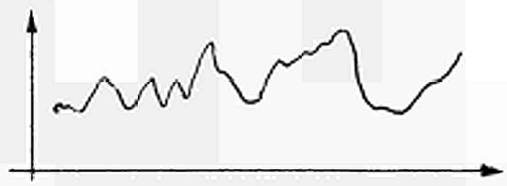
Fig. 2 - Aspects of signatures from surface textures

While taking and taking again such signals, good repeatability is normally obtained because the technique is good enough to allow a correct repositioning of the taster from one experiment to the other. The amplification is also stable so that no particular precaution is to be taken. The weak point, if any, could be that the tranverse speed of the taster changes a very small amount between two consecutive identity takings, due to an imperfect driving. This would result in a linear delay - to be compensated by computation - or into local extensions of signal in the horizontal direction, more difficult to compensate.

The signals from the focused transducer, as its is scanned in front of the seal have a typical shape, as in fig.3.



Seal nb. 1 in phase 0



Seal nb. 2 in phase 1

Fig. 3 - Aspects of signatures from VAK III seals

Its rounded pattern comes from the very measuring principle and from the limited number of visible defects (see again fig. 3 and fig. 5 in ref. 2). The apparent aspect of these signals may change in some extent between two experiments. This can be related to a slight change in the gain level, on the ultrasonic amplifier, along the vertical axis, or to the influence of temperature changes, or to the mechanical noise introduced by the rotating device.

As long as no automatic comparison was asked for, no particular difficulty has been encountered in getting acceptable reproducible signatures, for both kinds of markings (textures and cavities).

We systematically used an H.P. t,y, analog recorder on which we observe the result of the ongoing measurement. It can be said that it is a good demonstrating feature, as it shows the measured phenomenon as it comes out from the experiment.

4. Digitization and material

While trying to meet the automatic comparison requirements, screening tests had shown that the "texture" signals could be correctly described by series of 500 to 1000 values (a length of 10 mm being explored) and that 300 points were largely sufficient to digitize the curves typically obtained from an ultrasonic scanning. Fig. 4 is a block-diagram showing the material used for the purpose. It lists as follows:

- for surface texture measurements,
  - Special roughness taster (JRC)
  - Amplifier (Vibrometer)
  - Chart Analog Récorder $Y(t)$ (HP)

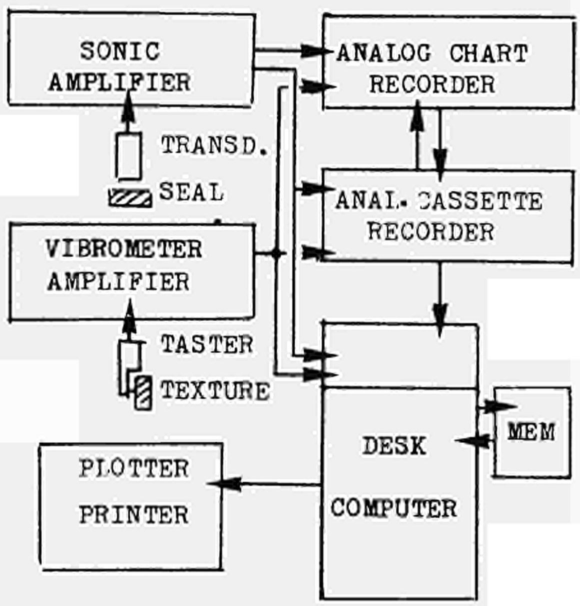


Fig. 4 - Block-diagram of the instrumentation used

- for ultrasonic measurements (VAK III seals):

  - Focussed Transducer 10 MHz (Aerotech)
  - Special scanning device (JRC)
  - Ultrasonic Amplifier (Sonic Mark I)
  - Special trigger (black-box)(JRC)

and for both measurements:

  - Analog Plotter (x,y) (HP 680)
  - Analog cassette Recorder (Philips)
  - Digital Voltmeter (HP 9872)
  - Desk Computer (HP 3872 A) with peripheral cassette memory

The special black-box had the purpose to insert a pulse into the identity signal at the start of an identity taking. This pulse is made adjustable in amplitude and in width. It is recorded on both tape recorder and plotter. Nevertheless it is not taken into account in the digitization process.

5. Computation

A programme has been first elaborated, which uses the Hewlett Packard Modified Basic Language and performed the calculation of the coefficient of correlation:

$$R = \frac{\sum(Xi-\overline{X})(Yj-\overline{Y})}{(\sum(Xi-\overline{X})^2 \sum(Yj-\overline{Y})^2)^{1/2}}$$

with reference to the conventional accumulators and with a shift value equal to

$$s = j - i$$

For the comparison of VAK III seals, the range of shift was -5 to +5 readings. This means that we were able to find a maximum value of R (near 1) within a shift exploration of about ± 1.7% of the total signal length (fig. 5).

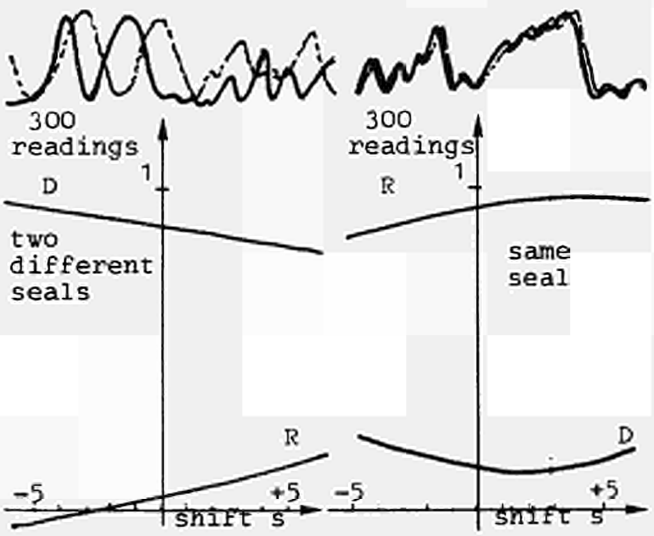


Fig. 5 - Example of a correlation chart

This gives an idea of the precision of the method. Some precaution was taken in the programme so that the second series of values (second curve) lost some 10 readings on the extremities, in order to allow the shifting being done.

For the VAK III seals, the "characteristic" as mentioned before was probably very stable, as we never had to make use of repeated data acquisitions (except that the transducer was rotated 2 revolutions for the visualization of each signature), nor did we apply smoothing process or any other modification of the original signature. This has to be related to the very kind of the signal which is fluctuating rather slowly with time.

However, for the study of the surface texture identification, the programme has been amplified with the scope of further parametrical study. The, in particular, encloses the possibility to choose various parameters:

- the maximum of the shift exploration
- the smoothing number (number of the averaged points)
- the number of readings
- the class number (vertical precision)
- the vertical expansion (to simulate a local inflation of the amplitude, in percentage)
- the length of signal to be expanded (in points)
- the vertical shift (zero deriving from its original position)

and calculates R, D, d, Δ and R^*:

$$R = \text{(see above)}$$

$$D = \frac{N\sum(Xi-Yj)^2}{\sqrt{\sum Xi}\ \sqrt{\sum Yj}}$$

$$d = \sum|Xi-Yj|$$

$$R^* = \frac{R}{\overline{X}-\overline{Y}}$$

$$\Delta = \frac{4\sum(Xi-Yj)^2}{N\ (\overline{X}+\overline{Y})^2}$$

Operators d and D were already calculated routinely in the first programme. They were useful to discriminate between the "same"/"different" seals situations. In fact, when the R(s) curve occasionally goes high in case of different seals, the "difference" curves: d(s) or D(s) are approximately flat. When, on the contrary, the curves come from the same seal, the d(s) and D(s) curves are "V" shaped and indicate clearly that the signatures are actually from a same seal (fig. 6).

A similar operator has been used for the purpose of weldings identifications[3].

Our parametric study is aimed at an estimation of the number of all possible

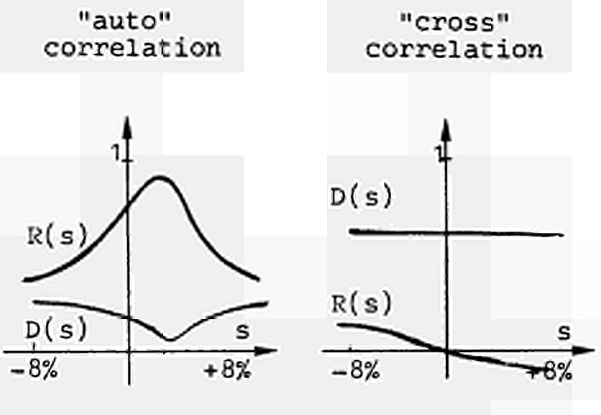


Fig. 5 - Example of $D_{(s)}$ curves

signatures one can obtained through a specified marking process. We expect to be able to estimate the probability of making a wrong statement, by evaluating the number of different possible curves one can theoretically conceive. This approach is different from the experimental way used by SNL[4] to estimate the probability density functions of the two statements : "different seals" or "same seal" with reference to the events actually observed.

The work is presently going on and different kinds of marking are prepared.

In the near future, we will buy a pocket-computer, in order to enable the acquisition and processing of the data with easy-to-transport material. Thus the desk-computer and peripherals, which we consider were necessary for study and demonstration exercises, both at JRC Ispra for the Pases "0" and at Kahl for the phases "1", would be replaced by a compacted material.

6. Conclusions

Signatures can be easily identified provided that the "characteristic" they represent be stable enough to allow that a kind of physics experiment can be repeated each time the object (or seal) is verified and that the instrumentation to do this be sufficiently precise. It is easier to compare two complicated signatures given by a stable characteristic, than comparing simple signatures delivered by an unstable characteristic.

In the first case, we have used successfully a method which simply calculates the coefficient of correlation and the "differences" between the two curves to be compared. There is no need to arrange the original signals in order to make them fitting, as it may be necessary in the second case.

However, a programme to assess the validity of a particular texture is being developed, which should lead to an estimation of the total number of possible signatures one can get from a same kind of marking process and help making a risk evaluation about wrong statements while saying: "same" or "different".

7. Acknowledgements

We wish to acknowledge the useful assistance given by Mr. O. Perusseau from E.N.S.E.M. Nancy - France, who is spending a training period in our laboratory and helped us in the optimization of the programs referred to in this paper.

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LAST PROGRESS OF THE VAK III SEALING SYSTEM

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Abstract

During the experimental demonstration performed in May 1984, at the Kahl reactor (FRG), the VAK III ultrasonic seals developed at JRC Ispra for the sealing of LWR fuel assemblies were found to work properly and to be easily reidentifiable.

Nevertheless, other improvements were indicated and requested concerning the handiness of the operating tools and a possible simplification of the correlation technique used on the spot, while performing a seal identification.

The work done, along with the progress obtained are presented, with a particular emphasis to the improving of the data processing and to the new adaptability of the identification instrument to various checking situations, in dry or in wet conditions, according to the requirements of the potential users or inspectors.

1. Foreword

The VAK III Sealing System is developed at JRC Ispra and tested in collaboration with FRG, in the framework of the Support Program to the IAEA.

It involves essentially special ultrasonic Seals for the safeguarding of BWR fuel assemblies and Special Devices to be used for checking and identifying them, in a nuclear plant, in conditions which should be acceptable to the Safeguards or Inspection Authorities.

Numerous field tests have been conducted in the recent years, at the Kahl facility (Versuchsatomkraftwerk), which is a BWR experimental reactor plant and was given its name (VAK) to the seals developed at Ispra purposely.

Since November 1983, the VAK III new version of sealing system appeared to fulfil the basic requirements from the operators, from the licensing authorities and from the potential users such as the safeguards organizations. The demonstrations performed at Kahl also indicated further progress to make and improvements to bring to the system.

It was also recommended to perform as much as possible tests at the Kahl facility before its closure, by the end of 1985 and according to its own operating plans. Neverthess, no campaign has been asked in May 1985, and a conclusive one has been announced in October-November 1985.

2. Introduction

In the previous ESARDA Conference (Venice - May 1984), we presented the VAK III Sealing System along with some results obtained with the new type of seals, at Ispra and during the Kahl demonstration in November 1983 [1].

During the week next to the Venice meeting, a second demonstration campaign was conducted at Kahl, and newly built seals (VAK III MEI b), prepared and pre-identified at Ispra, were installed on fresh fuel assemblies and reidentified on the spot.

The third campaign at Kahl, in October 1984 has proven to be an important milestone in the development of the VAK III Sealing System. In effect, all seals put in the reactor six or twelve months ago could be reidentified successfully; a batch of twenty-four new seals could be installed on other fresh fuel assemblies, and reverified with a new versatile Identification Equipment, either in water or in dry conditions. In addition, a novel Compact Instrument was presented and used for the first time at Kahl. It can perform the data processing which is required for a verification, directly on the spot in such a way that a transfer on a desk computer is no more necessary to do.

In this paper we report on the progress which we consider as fulfilling the feasibility requirements one can ask to such a Safeguards system. We also indicate still further improvements under consideration and possible extensions or applications we see for the future.

3. Kahl Demonstration in May 1984

Preliminary Tests

Before the campaign in May 1984, preliminary tests were performed at Ispra in order to check that the Random Identity Pattern of the VAK III seals was independent from:

- Temperature changes
- Transducer replacement

These tests have been already reported briefly in [2]. Their main result was that the Identity Patterns obtained from a same seal at different temperatures and/or with 3 different transducers of the same kind could be considered identical, and identified as such. The comparisons were based on the graphs observation and on the computation of the corresponding Coefficients of Correlation.

Actually, a seal behaves like a solid metallic body, insensitive to limited temperature changes. By turn, the ultrasounds route through it is not very much influenced, in particular, because of the relatively high energy level reflected by its built-in Strong Random Internal Defects and by the fact that the gain level used is in the range of 40 to 50 dB.

Conversely, Ultrasonic Transducers are items which are - by nature - more sensitive to larger temperature explorations. Therefore an upper temperature level of 40°C was chosen in order to avoid any damage to the probe. During our in-field experiments at Kahl, temperatures above 35°C were never encountered, in the pool, in the vicinity of a seal placed on an irradiated fuel assembly. Table I gives examples of such results and Fig.1 shows a correlation plot between 22°C and 40°C.

Change of Transducer (T4 - T11)

Seal :	*12*	*13*	*14*	*15*	*16*	*18*	*19*	*20*
Coef :	*0.96*	*0.91*	*0.95*	*0.97*	*0.96*	*0.91*	*0.94*	*0.95*

Change of Temperature (22° - 40°)

Seal :	*12*	*13*	*14*	*15*	*16*	*18*	*19*	*20*
Coef :	*0.97*	*0.96*	*0.97*	*0.95*	*0.95*	*0.96*	*0.95*	*0.98*

TABLE I

Sealing and Identification Operations

Eight newly built VAK III MEI b seals have been installed (Fig.2) on fresh LWR Exxon fuel assemblies. Then, they have been identified in the pool, on the stripping machine and identified again.

These new seals were 37 mm long, about 5 mm shorter than the previous types (VAK III MEI) and

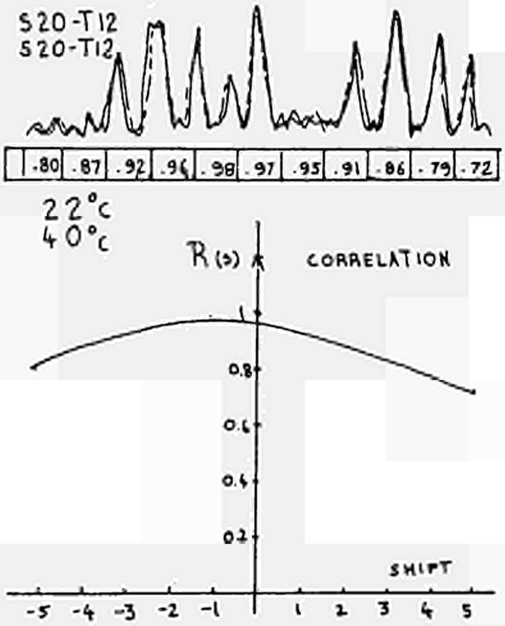

Fig. 1 Comparison between 22°C and 40°C

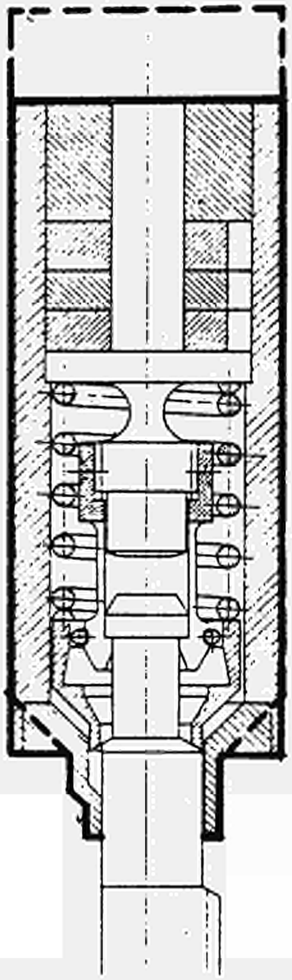

Fig. 2 The VAK III MEI b Seal

built to be scanned by the transducer of the identity tool, around a 3.5 mm radius (in place of a 3 mm radius, in the previous version). Therefore, it was necessary to modify the revolving device, in the immersed head of the identity tool.

Integrity Checks

With respect to the MEI, MEI b seals were modified as for the shape of the lower extremity of the breakable rod which acts as an ultrasonic mirror until the rod is broken. Clearer echograms were thus obtained and all seals could be verified with their corresponding fuel assemblies placed on the stripping machine.

Correlations

The identity measurements have been taken two times at Kahl; we call them Phase 1 and Phase 1' whereas the laboratory measurements are called Phase 0 (see also [3] p.30). Correlation calculations were made after the campaign in order to compare the measurements of the different phases.

Essential results are recalled in Table II., where the means of the "autocorrelation" factors and the related standard deviations are given.

Coef Correl.	Means	St. Dev.
IspraxIspra :	0.952	0.022
Kahl x Kahl :	0.937	0.066
Kahl xIspra :	0.944	0.071

TABLE II

Conclusion on the May 1984 Campaign

All operations planned by the D3 Working Group were carried out without difficulties. Part of the improvements pointed out in November 1983 were brought to the system and could be demonstrated. Nevertheless, the impossibility to perform data processing and computation, on the spot, just after the seals measurements, was considered as an handicap, even if the seal in itself was not involved.

4. Kahl Demonstration in October 1984

For this campaign the D3 Working Group had asked JRC to prepare a certain number of demonstrations. All of them have been conducted according to the plan and within the time imparted to the experiments. Doing this was made easier also because new equipments and instrumentation were introduced in the operating procedures.

Reidentification of Irradiated Seals

Seals installed in November 1983

Five VAK III MEI Seals placed in November 1983 have been reverified, in the pool, with the corresponding fuel assemblies transported onto the stripping machine. After one year of rest, the identification tool was found to work properly and no particular problem was encountered. The comparison between the measurements at one year of time distance were waited for with much interest. Correlations were calculated again on a desk computer located in a nearby room. The main result i.e. the "autocorrelation" coefficients between Phase 1 and Phase 2 are reported in Table III.

Seals installed in May 1984

Eight VAK III MEI b Seals placed in May 1984 have been reidentified too, in similar conditions but with a slightly different identity tool, as mentioned before. The fuel assemblies were transported on the stripping machine.

The "autocorrelation" results are reported in Table IV.

VAK III MEI Seals
Reidentification of 5 Irradiated Seals

Seal :	1	2	3	4	6
Coef :	0.97	0.97	0.94	0.96	0.98

TABLE III

VAK III MEI b Seals
Reidentification of 8 Irradiated Seals

Seal :	12	13	14	15	16	18	19	20
Coef :	0.96	0.97	0.94	0.94	0.98	0.91	0.86	0.95

TABLE IV

Integrity Checks

All seals were also verified and their integrity patterns were found unchanged with respect to the installation dates (6 or 12 months ago).

VAK III MEI b were confirmed to display easier readable patterns. Both MEI and MEI b seals were found "unbroken".

Handling Duration

Six irradiated fuel assemblies were handled during these reverification operations. Each of them bearing two or three seals, the medium handling time for the present demonstration was twenty minutes for one seal verified.

Installation and Identification of 24 New Seals

Operating in the Dry Storage

Eight fresh fuel assemblies located in the dry storage (revolving drum) have been sealed by hand, within half an hour. Then, the new Identity Tool shown in Fig.3 , which has been studied for

Fig. 3 New Identity Tool in Dry Condition

the seals identification in dry conditions, was used systematically and all 24 new seals had their identities acquired and stored on the new VAK 45 Instrument (see below) after 3 hours. This leads to a medium time of 7.5 minute per seal to be measured and takes into account the limited fuel assemblies handling time. For the demonstration, some seal was re-measured after removing the "dry tool". Correlation was calculated on the spot and gave a result higher than 0.980.

Operating on the Stripping Machine

After the installation of 24 new seals, the corresponding 8 fuel assemblies were transported into the wet storage. One fuel assembly was put on the stripping machine in order to demonstrate on the spot the use of the new Identity Tool and its capability of working in both dry and wet conditions. Fig.4 shows how the rotating head is now immersed in water, which allows to abandon the long rotating transmission used in the previous

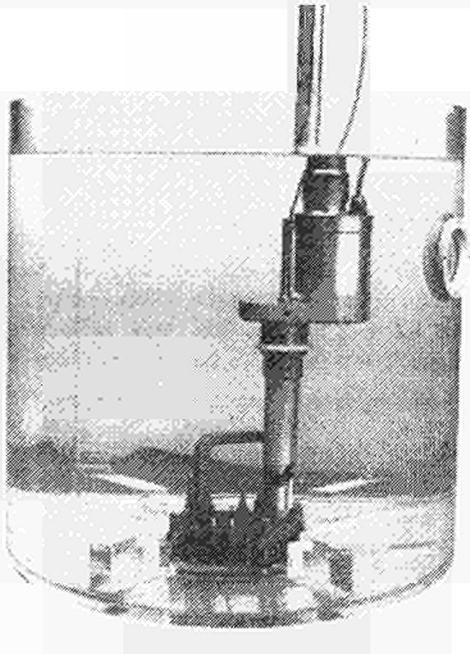

Fig. 4 New Identity Tool Immersed

demonstrations, where the motor was kept out of water.

The three seals on that fuel assembly were re-measured. The signatures were compared with the ones given in dry conditions and gave:0.986, 0.990 and 0.987 respectively.

Operating on Wet Storage Racks

After the eight preceeding fuel assemblies had been installed in their normal wet storage position, we tried to demonstrate the capability of the new Identity Tool to operate directly in the bottom of the pool, which was made possible through the addition of as many extension tubes as necessary to reach a depth of about 8.5 m from the operator's hands. This could be done and the operator had no special difficulty in "seizing" the seals and performing the signatures acquisitions. One seal was identified within 4 minutes on the spot, the other two later on. Correlation figures were above 0.950.

New Correlation Compact Instrument

The new compact instrument called VAK 45 was developed in order to offer the inspectors a possibility of identifying seals either on the spot, or, after a certain delay, back at their office.

This instrument was presented for the first time in October 1984 in an effort to anticipate solution to further requests to come. It embodies mainly a Minicomputer, a Printing Unit, a Light Tape Recorder and (at the moment) a conventional, well tested, reliable Ultrasonic Instrument (see also [3], § 5 and § 6). There have been discussions at JRC as for its presentation. Thus a first VAK 45 instrument as in Fig.5 and a second one, as in Fig.6 where the Sonic Instrument has been kept aside (VAK 18).

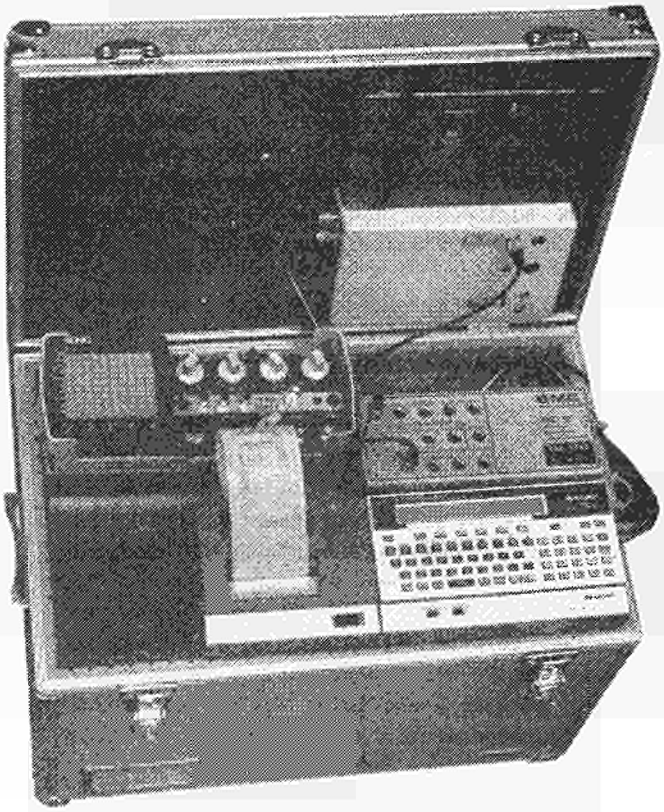

Fig. 5 Compact VAK 45 Box used at Kahl

The Software for this instrument has been studied in order to give all information relevant to a seal signature acquisition or correlation with a previous measurement available on a short strip of paper (between 10 and 24 cm according to the chosen procedure. The conduction of the program is made on a dialogue basis ("acquisition Y/N ? correlation Y/N ? Nb of Measurement ? with a graph ? a shifting ? etc ...").Data are stored normally on conventional sound cassettes. A "Tram" interface can be used in order to reduce the duration of data transfers from the recorder to the computer memory and vice-versa. Floppy disk memories can also be used.

Correlation Results

For all 24 seals used in that campaign, signatures were acquired at least two times. At JRC Ispra (Phase 0) and at Kahl (Phase 1 and 1' in some cases). 276 cross-correlations and 24 auto-correlations were calculated systematically with the new instrument. Part of these results is given in Table V which indicates 15 cross correlations of seal n°22 (KahlxKahl) and 24 auto correlations (IspraxKahl).

22x34:0.234	35:0.429	36:0.315	37:0.266	39:0.487
40:0.375	41:0.302	42:0.268	44:0.131	45:0.208
46:0.315	47:0.158	48:0.438	49:0.278	50:0.297
22: 0.984	23:0.951	24:0.965	26:0.977	29:0.969
30: 0.994	31:0.959	32:0.960	33:0.915	34:0.956
35: 0.982	36:0.943	37:0.944	39:0.971	40:0.974
41: 0.967	42:0.974	44:0.979	45:0.973	46:0.972
47: 0.983	48:0.988	49:0.990	50:0.963	

TABLE V

A general aspect of these results is given in the histogram which has been plotted for all these correlations (Fig.7).

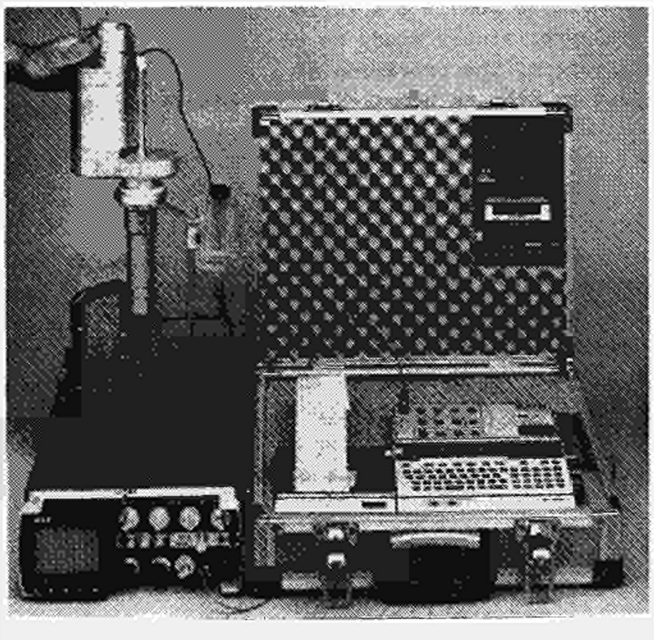

Fig. 6 Identity Tool and Instrument

The fac-simile of a correlation calculation strip is given in Fig.8.It deals with the comparison of seals n° 22 and 34.The zero shift estima-

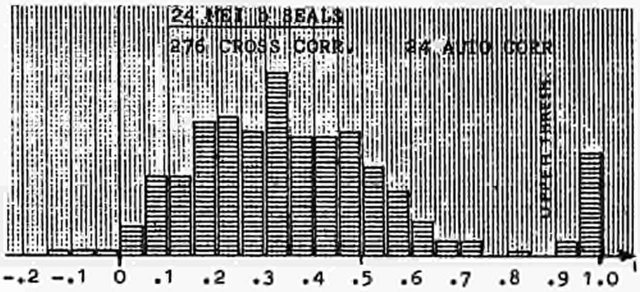

Fig. 7 Histogram of 300 correlations

tion has given: 0.234, which is reported in Table V. Note that the signatures of two different seals are synchronized on their higher peak, which tends, for about a tenth of the signal length, to correlate two different signals, thus increasing by a small amount the resulting "cross cor - relation" coefficient.

Conclusion on the October 1984 Campaign

All operations on irradiated seals were performed with no particular difficulties. Reidentifications carried out with the first equipments gave good results.

Other 24 new seals were installed while a versatile identity tool was demonstrated in the dry and in the wet storages. The novelties were the possibility to identify a seal in air or in the bottom of the pool, with as same equipment.

A new compact instrument, with its software, was presented and systematically used. It represents a progress as for the checkings practicability and transportability.

5. Future Views

While an Assessment Study is being conducted since the beginning of 1985 by the interested Safeguards Authorities, people in the laboratories who consider that the VAK III Sealing System has clearly met its Feasibility Requirements (see [3]) are nevertheless contemplating further improvements to bring to the VAK III seal, taken as a LWR fuel element seal, in case of pre-industrial requirements which could come up. They also study

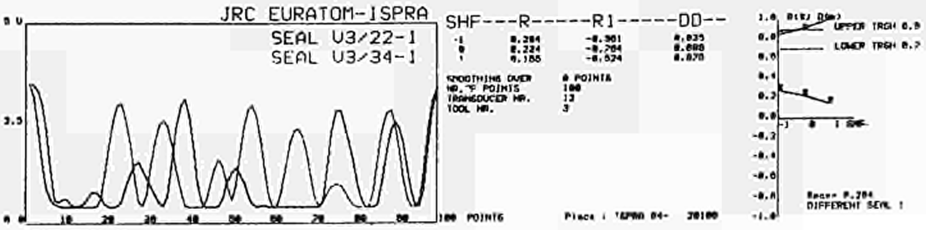

Fig.8
Fac-simile of a
Correlation Strip

how to apply this technology, which is characterized by ultrasonically interrogated randomly distributed internal defects built in the seal structure, to other Safeguards items or seals.

Further Improvements to VAK III

Fastening Technique

In order to avoid asking a special extended tie-rod end for fastening the seal on the fuel assembly, a solution is being studied which would use a special nut for fastening the VAK III seals.

Reduced Length

Efforts are made to reduce the VAK III seal length from 37 mm to 34 mm, without reducing the zone dedicated to identity in the upper part of the seal. This involves some problems as for the brazing process being used for "fixing" the defects.

Integrity inside Identity

Preliminary tests have been carried out to assess the possibility to incorporate the "integrity signal" inside the "identity signal" of a same seal. Doing this would simplify the checking techniques because only one measurement would be necessary to perform, while verifying both identity and integrity of a seal. The problem is to weaken the identity zone of the seal in a controllable or predictable way. Should this study be successful, it would allow to work with the same probe and the same tool while interrogating a seal.

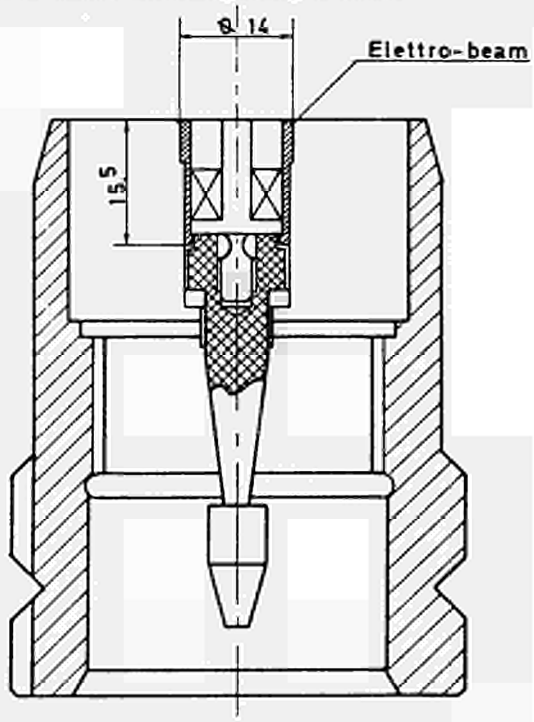

Fig.9 Application to a CANDU Seal

New Compact Instrument

For the future, in case of requirement from the Safeguard Authorities, the size of the controlling instrumentation could be still further simplified. To date, the VAK 45 Box, for instance, was used mainly for the feasibility demonstration to the D3 Working Group. If the whole system is accepted, then the electronics could be reduced to its essential functions. The VAK 18 Box presented in Fig.6 would, for instance, embody the electronics of the ultrasonic instrument seen on the left hand side. It seems to us wise to wait for a decision about the whole system before entering into details which would better chosen in collaboration with users.

Extensions to Other Systems

The direct application of the VAK III MEI technique to Spent Fuel Stack Seals (CANDU like seals) is under consideration at Ispra. Fig.9 is a representation of a prototype under development.

PWR Fuel Assemblies

It is questionable whether to "seal" the PWR fuel assemblies or not. The ultrasonic seals are probably a possible solution provided that an actual preliminary study be conducted with the manufacturers. The provision of a certain number of ideas is seen as beneficial to the whole development.

Sealing Bolts

Another possible field of application is the Safeguarding of Containers. Large bolts are used for tightening lids. Their dimensions (L=160mm, d=14mm) make it possible to incorporate a VAK III seal (L=37mm, d=13mm) in their head. Fig.10 shows a schematic representation of such a sealing-bolt in a configuration similar to the one used presently by BNFL. Only the bolt's head is represented.

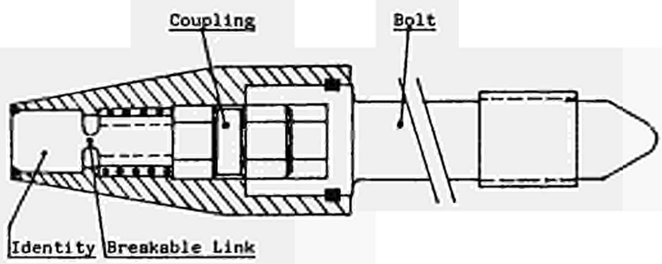

Fig.10 Example of a Sealing-Bolt

6. Conclusion

The last progress realized with the JRC developed VAK III Sealing System has been presented. Two campaigns conducted at the nuclear facility of Kahl in 1984 have been described and their results indicated.

It is now clear that such a sealing system behaves correctly under irradiation; can be identified in water or in dry conditions; offers to the inspecting users a flexible possibility to compare the seals one with respect to the others.

The main achievements can be summarized as follows:

Vak III seals can be put, identified and integrity checked:

- In dry conditions (manufacturer plant)
- In the dry storages
- On stripping machines
- Directly in the wet storage racks
- On fresh or irradiated fuel assemblies
- They can be extracted from an irradiated fuel placed on a stripping machine and breaking forces can be measured

Thanks to the use of a Compact Instrument, it is possible to identify a seal on the spot within about 7.5 minutes, which is the medium duration observed at Kahl.

Although no particular encouragement has been indicated to date for a further application of that sealing system, Ispra is considering possible additional improvements to bring and extension applications to different other Safeguards items.

A "last but not least" campaign at Kahl is being prepared for October 1985.

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European Communities — Commission

EUR 10242 — VAK III seals and sealing system

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