EUR 5108 e

COMMISSION OF THE EUROPEAN COMMUNITIES

ULTRASONIC SIGNATURE

by

E. BORLOO and S. CRUTZEN

1974

Joint Nuclear Research Centre, Ispra Establishment — Italy

Materials Division

LEGAL NOTICE

This report is on sale at the addresses listed on cover page 4

at the price of B.Fr. 60,–

Commission of the
European Communities
D.G. XIII - C.I.D.
29, rue Aldringen
Luxembourg

December 1974

EUR 5108 e

ULTRASONIC SIGNATURE by E. BORLOO and S. CRUTZEN

Commission of the European Communities
Joint Nuclear Research Centre — Ispra Establishment (Italy)
Materials Division
Luxembourg, December 1974 — 54 pages — 29 figures — B.Fr. 70,—

The unique and tamperproof identification technique developed at Ispra is based on ultrasonic Non-Destructive-Techniques.

Reading 'fingerprints' with ultrasonic requires high reproducibility of standard apparatus and transducers.

The present report gives an exhaustive description of the ultrasonic technique developed for identification purposes. Different applications of the method are described.

EUR 5108 e

ULTRASONIC SIGNATURE by E. BORLOO and S. CRUTZEN

Commission of the European Communities
Joint Nuclear Research Centre — Ispra Establishment (Italy)
Materials Division
Luxembourg, December 1974 — 54 pages — 29 figures — B.Fr. 70,—

The unique and tamperproof identification technique developed at Ispra is based on ultrasonic Non-Destructive-Techniques.

Reading 'fingerprints' with ultrasonic requires high reproducibility of standard apparatus and transducers.

The present report gives an exhaustive description of the ultrasonic technique developed for identification purposes. Different applications of the method are described.

EUR 5108 e

ULTRASONIC SIGNATURE by E. BORLOO and S. CRUTZEN

Commission of the European Communities
Joint Nuclear Research Centre — Ispra Establishment (Italy)
Materials Division
Luxembourg, December 1974 — 54 pages — 29 figures — B.Fr. 70,—

The unique and tamperproof identification technique developed at Ispra is based on ultrasonic Non-Destructive-Techniques.

Reading 'fingerprints' with ultrasonic requires high reproducibility of standard apparatus and transducers.

The present report gives an exhaustive description of the ultrasonic technique developed for identification purposes. Different applications of the method are described.

COMMISSION OF THE EUROPEAN COMMUNITIES

ULTRASONIC SIGNATURE

by

E. BORLOO and S. CRUTZEN

1974

Joint Nuclear Research Centre, Ispra Establishment — Italy

Materials Division

ULTRASONIC SIGNATURE :

1. INTRODUCTION 5

2. BASIC PRINCIPLES OF ULTRASONIC TESTING OF MATERIALS 5

3. PRINCIPLE OF ULTRASONIC IDENTIFICATION 8

4. USING A NATURAL MARK FOR IDENTIFICATION PURPOSES 9

5. USING ARTIFICIAL MARKS FOR IDENTIFICATION PURPOSES 13
    5.1. Choice of the type of inclusion 13
    5.2. Choice of the frequency of the ultrasonic transducer 18
    5.3. Other characteristics of the ultrasonic transducer 19

6. DEAD ZONE 32

7. PRACTICAL CASES OF IDENTIFICATION WITH ARTIFICIAL MARKS 33
    7.1. Identification of an MTR type fuel element plate 33
    7.2. The use of seals for identification purposes 35

8. GENERAL CONSIDERATIONS ON THE IDENTIFICATION CHAIN 49

9. DATA TREATMENT 51

10. CONCLUSIONS 52

11. REFERENCES. 53

1. INTRODUCTION

1.1. Most of the identification techniques proposed for safeguarding fissile materials must give "tamperproof unique" identities and not only an identification number. These techniques make use of certain random properties of the structures containing the fissile material or of the fissile material itself.

The physical or technological process used to reveal the properties assuming the unique identity might be /¯ref. 16_7

- optical techniques
- radiographic techniques
- electromagnetic techniques
- acoustic techniques

1.2. The development work performed at the J.R.C. ISPRA on unique identification methods is principally based on ultrasonic Non Destructive Techniques.

1.3. The aim of this report is to give an exhaustive description of the ultrasonic technique developed for identification purposes. The different applications of the method are described.

2. BASIC PRINCIPLES OF ULTRASONIC TESTING OF MATERIALS

In very general terms, the use of ultrasonics for material testing involves the conversion, with a piezoelectric transducer, of an electrical signal into a high frequency mechanical vibration. This vibration which is a pure pressure wave, when sent into a specimen propagates itself until a change in acoustic impedance results in a partial or total reflection of the pressure wave.

The reflected part of the waves produces a mechanical vibration of the piezoelectric element which, due to the piezoelectric effect, generates an electrical signal that after amplification can be visualized on an oscilloscope screen (Fig. 1).

This system is called the reflection technique.

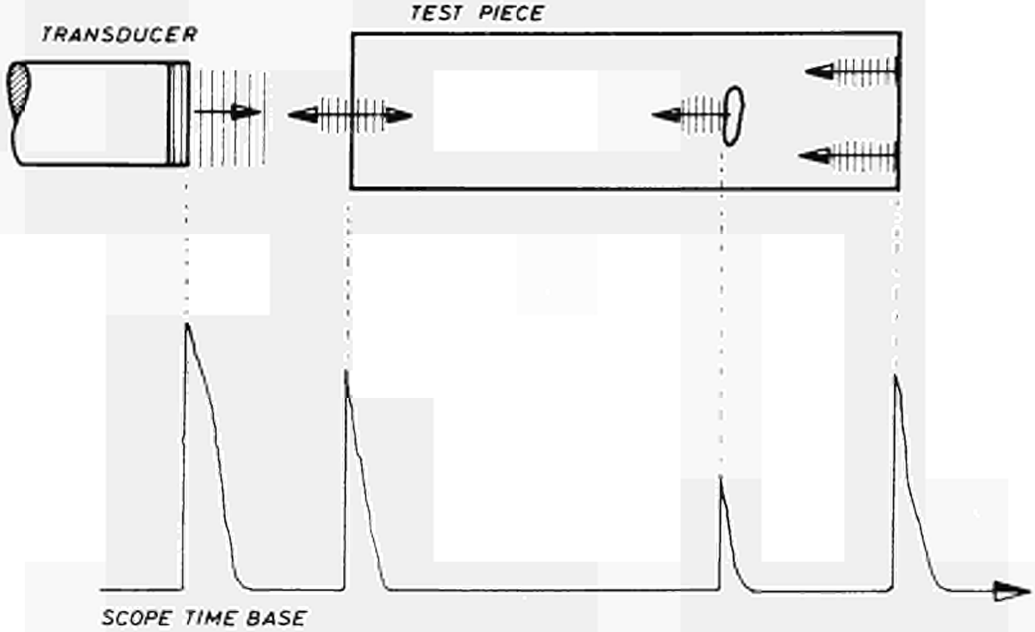


Fig. 1 - Principle of the reflection technique

Reflections of the ultrasonic beam are obtained from the entry surface, the flaw and the back surface of the specimen (Fig. 1). The vertical pulses, indicating the presence of echoes, are displayed along the horizontal base line of the oscilloscope and represent the elapsed time or distance in the sample. This means that the respective echoes are in the same relative position as the reflecting surfaces. Their amplitudes are proportional to the quantity of reflected energy. The commonly used frequencies for ultrasonic testing are between 1 and 15 MHz. At these frequencies, the acoustic impedance (acoustic impedance is the product of the density of the particular medium and the acoustic velocity) of air is so unfavorable to the propagation of ultrasonic waves that the transducer has to be coupled directly to the object to be tested.

This coupling method is inconvenient if reproduceable results are expected and particularly when a mechanical scanning has to be performed.
Since water, unlike air, is a good conductor of ultrasonic energy, it is used as a medium to transmit the ultrasonic wave produced by the crystal to the material to be tested.
Considering Fig. 1, when the transducer is energized, a burst of sound waves is imparted to the water. This burst travels through the water and in a few micro-seconds reaches the test piece. At the water to metal interface, the acoustic wave is partially reflected, due to the impedance mismatch, and partially propagated into the metal part. The burst energy is split into two portions, each traveling in opposite directions along the same axis.

The wave propagating into the test piece, when reaching the flaw splits again due to the acoustic mismatch as it did at the water metal interface. The only energy continuing in the metal part is that which has circumvented the defect. This part of the sound wave is then reflected from the bottom of the test piece.

Due to the different distances traveled, the various portions of the original pulse arrive back at the transducer at different times. When this information is displayed on an oscilloscope, it appears as a series of pulses as shown on the bottom line of Fig. 1.

For further literature, see Ref. (1) and (2).

3. PRINCIPLE OF ULTRASONIC IDENTIFICATION

As mentioned in § 2, a flaw, corresponding to an acoustic impedance mismatch, reflects partially or in totality the ultrasonic pressure wave. This reflection (echo) when visualized on the screen of the ultrasonic instrument, contains two items of information which are suitable for identification purposes:

1) an amplitude information, proportional to the geometric dimensions and to the orientation of the flaw and
2) a distance information given by the depth of the flaw in the test piece.

In Fig. 2, an ultrasonic transducer T is water coupled to two different test pieces. Each test piece contains a flaw of different dimensions and at a different position in the test piece.

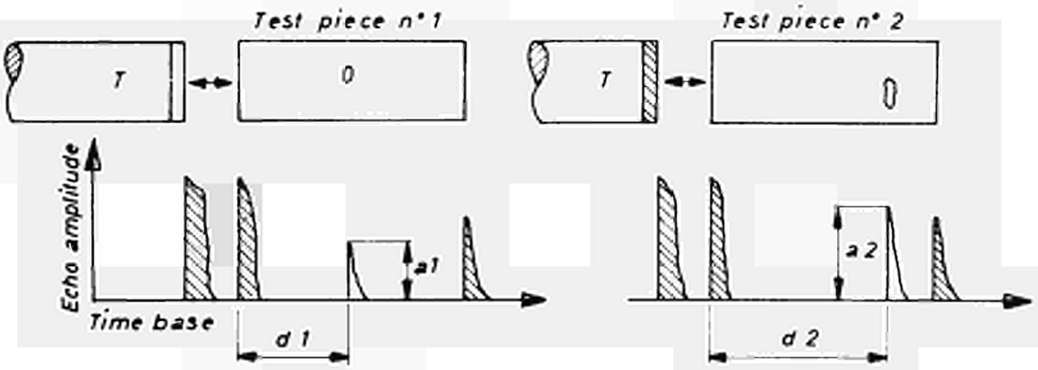


Fig. 2 - Example of ultrasonic identification

On the lower part of Fig. 2, all the echoes obtained on the ultrasonic instrument screen are shown. From left to right, we see first the transmission pulse, then the echo due to the reflection of the sound wave at the interface of the test piece, then the echo due to the internal flaw and finally the back echo of the test piece.

Considering only the echo of the internal flaw, we have the possibility of identifying both test pieces by their relative echo amplitudes and echo distances.

Test piece n°1 : amplitude a 1, distance d 1
Test piece n°2 : amplitude a 2, distance d 2

4. USING A NATURAL MARK FOR IDENTIFICATION PURPOSES

In many cases, an inherent natural mark can be found which, when adequately scanned with an ultrasonic transducer, can produce a document supplying a unique identity of the scanned piece. For instance, grain size, structure, welded seam geometry, bonding, natural defects... are some parameters which might be used to discover an ultrasonic signature.

The inspection technique developed in 1969 for fuel element end plug welds (Ref. 3) is a practical example of how the obtained document could be used to identify individual fuel pins.

In practice, the information is retrieved in the following way.
An ultrasonic transducer is positioned under water perpendicularly to the welded zone of a tube (Fig. 3). At the water-tube interface, one part of the pressure wave is reflected and produces the first echo.

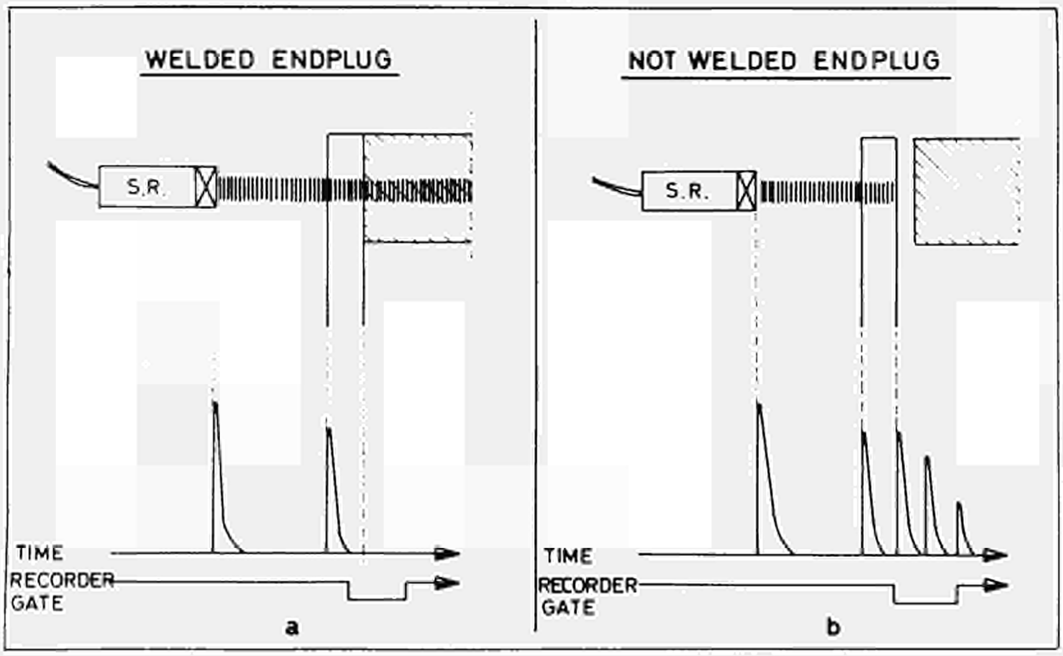


Fig. 3 - Weld control principle and ultrasonic instrument screen indications for a) welded end plug and b) unwelded end plug.

The other part of the acoustic pressure wave travels into the tube wall and if welding is present, travels through the end plug. If no weld exists, the air gap between the sheath and the end plug is responsible for the complete reflection of the residual energy on the inner surface of the tube. This reflection produces the second echo on the instrument screen. The multiple reflections between the internal and external surfaces of the tube produce a series of echoes with decreasing amplitudes.

The difference of image obtained on the cathode ray tube for a welded or an unwelded zone is used to inspect the quality of the entire weld seam. Setting the recorder gate just after the first echo, no signal will be present for a welded zone; on the other hand, one or more echoes will be in the gate for an unwelded zone.

For making the measurement, the necessary elements are (Fig. 4): a weld exploration mechanism, an ultrasonic instrument, a quantizer and a facsimile recorder. The water tank contains the tube to be tested and the ultrasonic transducer.

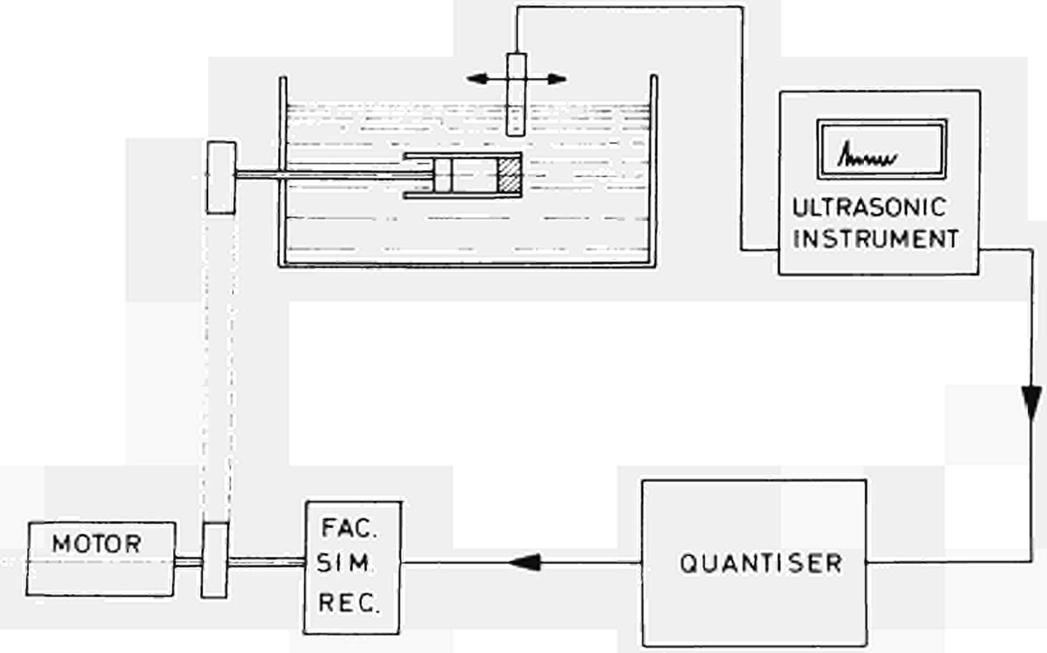


Fig. 4 - Measurement set up

The exploration mechanism must provide the rotation of the tube and also, in order to insure perfect synchronization, the rotation of the facsimile recorder drum. Another part of the exploration mechanism provides for an axial displacement of the transducer over the weld seam. The quantizer is an electronic apparatus which enables electrical analogue signals to be quantized into predetermined levels before feeding them to a facsimile recorder.

The facsimile recorder makes its recording by drawing an electrosensitive paper between two electrodes when current, related to the analog signal, is passed between them. In the MUFAX recorder (Ref. 4), one electrode is a stainless steel blade and the other a nickel chrome wire helix mounted on the periphery of a rotary drum. As the drum totates, the point of contact between the paper and the electrodes moves across the paper in a series of closely spaced lines. Electrolytic action at the point of contact causes a black deposition of iron from the blade onto the paper. The drum rotates in time with the tube to be tested so that one rotation corresponds with one line on the recorder paper. The advance of the paper is produced by a gear-down action in the recorder itself.

On the obtained document, (Fig. 5), the abscissa shows the angular position of the developed tube, the ordinate the length of the welding in the direction of the tube axis.

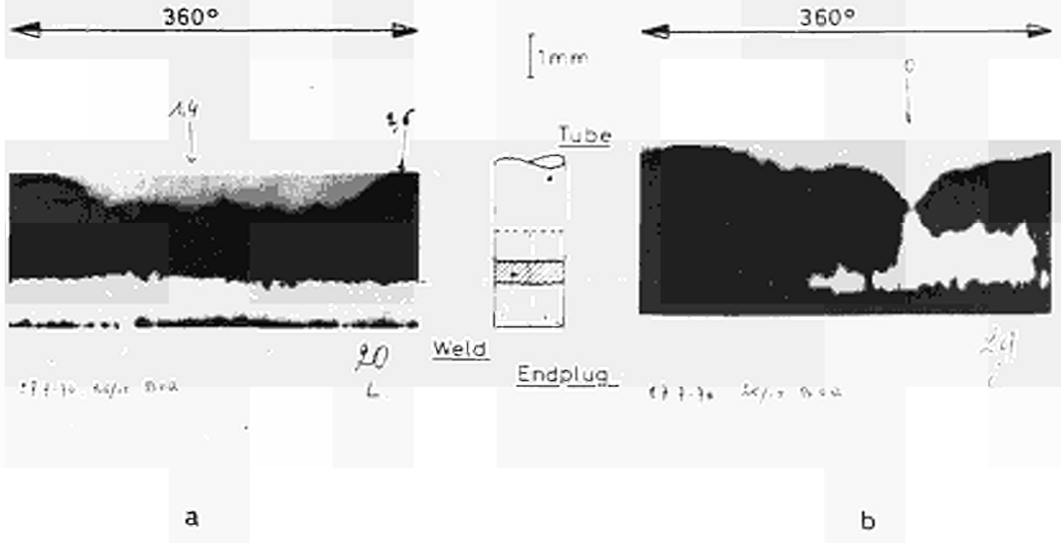


Fig. 5 - Obtained document for a welded (a) and an unwelded (b) end plug.

As can be seen on both weld control documents, the weld seam geometries differ greatly from one to another. Each geometry is unique and specific to the weld concerned. This document could easily be used as an identity or signature for the corresponding fuel pin.

The use of a natural mark for indentification purposes is not always the ideal solution. It often leads to a rather difficult reading of the identity and may also be difficult to transform into digital information if the identity has to be computerized. Therefore, a more convenient solution is to mark the test piece if possible, with artificial inclusions.

5. USING ARTIFICIAL MARKS FOR IDENTIFICATION PURPOSES

It is possible to introduce into materials artificial marks which can be ultrasonically detected. If these artificial marks (inclusions) have good reflection conditions for the ultrasonic wave and if they are randomly dispersed, the ultrasonically obtainable information is unique and corresponds to a real identity or "signature" (finger print).

5.1. Choice of the type of inclusion

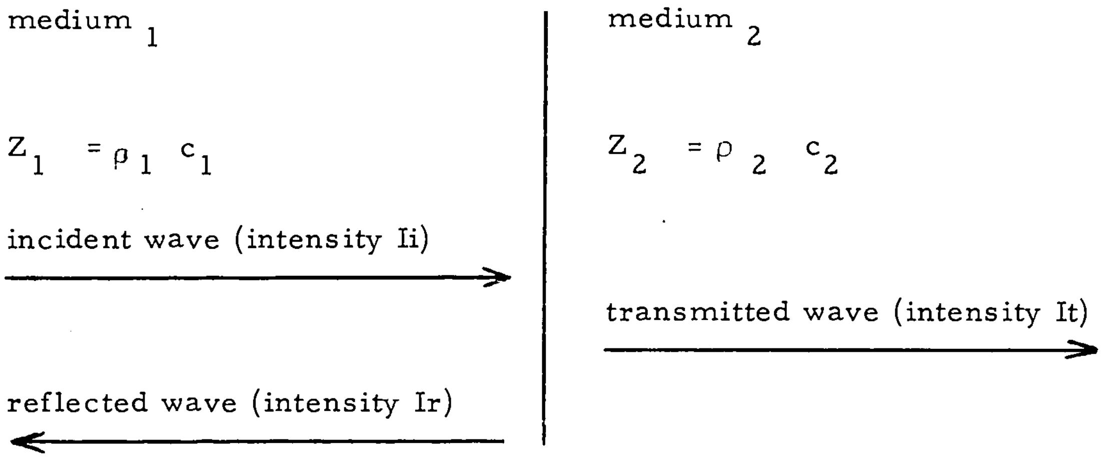
Every material has a characteristic acoustic impedance, Z, which is defined as the product of density ρ and the wave velocity c (usually longitudinal). Impedance is then given by:

$$Z = \rho\, c \quad \mathrm{kg/m^2/sec.}$$

where ρ = density, kg/m^3

c = velocity, m/sec

When a plane wave propagating through a medium of acoustic impedance Z_1 encounters under normal incidence another medium of acoustic impedance Z_2, one part of the wave is reflected and another part is transmitted into the second medium.



The ratio between reflected wave intensity, Ir, and incident wave intensity, Ii, is given by the reflection coefficient R (Ref. 1)

$$R = \frac{Ir}{Ii} = \left(\frac{Z_2 - Z_1}{Z_2 + Z_1}\right)^2 \qquad (1)$$

The ratio between transmitted wave intensity, It, and incident wave intensity, Ii, is given by the transmission coefficient T.

$$T = \frac{It}{Ii} = \frac{4\, Z_1\, Z_2}{(Z_1 + Z_2)^2} \qquad (2)$$

The sum of the reflection and transmission coefficient is unity; i.e.

$$R + T = 1$$

The above defined reflection and transmission coefficients refer to the relative intensities of the reflected and transmitted wave in relationship to the incident wave.

If we consider the relative acoustical pressure, we have: (Ref. 1)

$$R' = \frac{Z_2 - Z_1}{Z_2 + Z_1} \quad \text{and} \quad T' = \frac{2\ Z_2}{Z_2 + Z_1} \qquad (3)$$

As an example, we calculate R' and T' on the water/steel interface taking into account the equation (3)

Z_1 (water) $= 1,5 \times 10^6$ kg/m^{2}s

Z_2 (steel) $= 45 \times 10^6$ kg/m^{2}s

Then

$$R' = \frac{45 - 1,5}{45 + 1,5} = 0,935 \qquad T' = \frac{2.45}{45 + 1,5} = 1,935$$

Expressed in percentage the reflected wave has 93,5% of the sound pressure of the incident wave. The transmitted wave has a sound pressure of 193,5% of the incident pressure.

Considering the steel/water interface, we obtain following equation (3):

$$R' = \frac{1,5 - 45}{1,5 + 45} = -0,935 \qquad T' = \frac{2.1,5}{1,5 + 45} = 0,065$$

In percentage, the reflected wave has - 93.5% of the incident sound pressure and the transmitted pressure 6.5% of the incident pressure.

The negative sign indicates a phase inversion in relationship to the incident wave.

It seems strange that the sound pressure exceeds 100%.

However according to the intensity equation:

$$I = \frac{1}{2} \frac{P^2}{Z} \quad \text{W/m}^2$$

where P = sound pressure in N/m^2

Z = acoustic impedance in kg/m^{2}s

the intensity (or energy per unit time and unit area) is calculated not only from the sound pressure but also in function of the acoustic impedance. As the acoustic impedance of steel is much greater than the impedance of water, the intensity of the transmitted wave is much smaller in steel than in water but the sound pressure is much higher.

If now, for identification purposes, we intend to put inclusions of one material into another, the most important factor to take in account is their relative acoustic impedance.
In fact, looking at equations (1), (2) and (3), it is clear that the best reflection coefficient is obtained when $Z_1 >> Z_2$ or $Z_1 << Z_2$.

Table 1 indicates the reflection coefficients of some materials which have been taken into consideration for identification purposes. These values taken from Ref. 5 were calculated on the basis of equation (3). Phase reversal is characterized by a negative value of R and occurs in the case of reflection on a sonically softer material. As it is more convenient (for instrumentation purposes) to obtain a reflected signal in phase, the reflection conditions we have to look for are:

$$Z_1 << Z_2$$

MATERIAL Z_2 Z_1		Copper	Nickel	S. Steel	Aluminum	Silver	Molybdenum	Tantalum	Tungsten	Water	Plexiglass
	Z_1	41	50	44,8	17,3	38	64	69	99	1,48	3,2
Plexiglass	3,2	+ 86	+ 87	+ 86	+ 68	+ 84	+ 90	+ 88	+ 93	- 37	0
Aluminum	17,3	+ 42	+ 47	+ 45	0	+ 37	+ 57	+ 51	+ 70	- 84	+ 68
Stainless Steel	44, 8	- 32	+ 29	0	- 45	- 91	+ 16	+ 86	+ 36	- 94	- 86
Water	1,48	+ 93	+ 94	+ 93	+ 84	+ 92	+ 95	+ 94	+ 97	0	+ 37

Z_1 = acoustic impedance for tlongitudinal waves in 10^6 kg/m^{2}s.

Table 1 : Reflection coefficient in % at boundaries and normal incidence.

5.2. Choice of the frequency of the ultrasonic transducer

In order to determine the most convenient frequency for detecting inclusions in a material, different parameters must be taken into account. Most important factors are: the dimensions of the inclusions, the grain size of the basic material and the absorption of the ultrasonic wave in the basic material.

5.2.1. Dimensions of the inclusions

A longitudinal wave traveling through a medium Z_1 is reflected by an inclusion Z_2 if the dimension of this inclusion is large compared with the ultrasonic wavelength. In other words, if small inclusions have to be considered, a high frequency transducer has to be used ($\lambda = \frac{c}{f}$). In Table 2, some values of the wavelength are given for the basic materials taken into consideration for identification purposes.

frequency material	1 MHz	5 MHz	10 MHz	15 MHz	20 MHz
Plexiglass	2,7	0,53	0,27	0,18	0,13
Aluminum	6,32	1,26	0,63	0,42	0,31
S. Steel	5,90	1,18	0,59	0,39	0,29
Water	1,4	0,29	0,14	0,09	0,07

(mm) = $\frac{c}{f}$ c = sound velocity f = frequency

Table 2 : Wavelength in different materials as a function of the frequency

5.2.2. Grain size structure

The grain size of the basic material has to be considered with reguards to the wavelength of the ultrasound. No defined rules exist (at this proposal) while grain size cannot be considered as an independent parameter; many others, difficult to determine, are also involved: anisotropy, grain boundaries, The effect of grain size for non destructive testing with ultrasonics is that when the grain size is equal or greater than the half wavelength of the ultrasound scattering may occur.

By scattering we mean that the ultrasonic wave is divided into different waves propagating in radom directions. This phenomenon, repeated at each grain, produces a diffusion of the ultrasonic wave so that only a very small part of the incident energy returns to the transducer.

For the practical determination of the ultrasonic frequency in function of the grain size, an experimentally defined guide-line could be: (Ref. 1)

- when grain size is of the order of magnitude of between 0.001% and 0.01% of the ultrasonic wavelength no scattering occurs; on the other hand for 0.1% of the wavelength, scattering can be so strong that no further control is possible.

5.2.3. Absorption

Absorption is the direct conversion of sound energy into heat.

The absorption has the effect of weakening the transmitted energy and also the energy of the echoes from the inclusions or the backwall. As a general rule, it may be considered that the absorption is directly proportional to the frequency.

The absorption effect can be compensated by the ultrasonic instrumentation increasing the transmission pulse voltage or the amplification.

5.3. Other characteristics of the ultrasonic transducer (6.7.8.)

5.3.1. Diameter of the piezo-electric element

As in optics, the directivity of the propagated energy is determined by the D/ ratio, where D is the diameter of the piezo-electric element and λ the ultrasonic wavelength. The dispersion angle of a piezo-electric element of one wavelength diameter is approximately 45 degrees.

When $D = 4\lambda$, this angle is about 10 degrees.

In order to obtain good directivity, i.e. with a dispersion angle of less than 5 degrees, a minimum D/λ ratio of 20 is recommended. Table 3 lists for frequencies between 0,5 and 30 MHz, the diameter of the piezo-electric material corresponding to 20 wavelengths.

Frequency MHz	λ (mm) in water	20 λ (mm) in water
0,5	2.98	59.6
1	1.49	29.8
2.25	0.662	13.2
4	0.372	7.44
5	0.298	5.96
6	0.248	4.96
10	0.149	2.98
12	0.124	2.48
15	0.099	1.96
20	0.074	1.48
30	0.050	1.00

Table 3 : Recommended minimum crystal diameter (20 λ)

5.3.2. Pressure distribution along the acoustic axis of the transducer

The pressure distribution along the axis, for a circular, flat piezo-electric element is given by the mathematic relation: (6)

$$P = 2 E \sin (ka^2/4x) \qquad (4)$$

where P = pressure on the axial line

E = relative maximal amplitude

a = radius of the piezo-element

x = distance

k = $(\omega/c) = (2\pi f/c = (2\pi/\lambda)$

c = sound propagation velocity

λ = wavelength of the ultrasound

Developing the relation (4) for different points along the transducer axis, the curve of Fig. 6 is obtained for a 5 MHz transducer, 20 mm diameter, immersed in water. The maximal intensity points correspond to the values of x for which the term:

$$\sin\ (ka^2/4x) = 1$$

These maxima appear for:

$$x = ka^2/2\pi, \qquad ka^2/6\pi, \qquad ka^2/10\pi$$

The minimum intensity points correspond to the values of x for which the term:

$$\sin\ (kx^2/4x) = 0$$

These minima appear for:

$$x = ka^2/4\pi, \qquad ka^2/8\pi, \qquad ka^2/12\pi$$

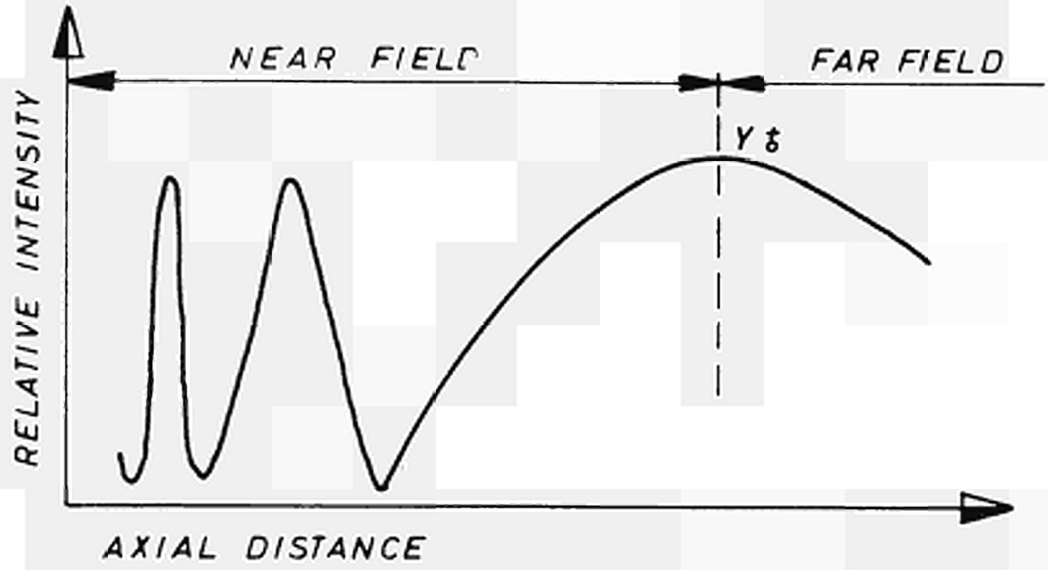


Fig. 6 - Axial pressure distribution

The radiation pattern of a transducer is composed of two energy zones, the near field (or Fresnel zone) and the far field (or Fraunhofer zone). In contact testing, both zones are involved, by immersion testing only the far field is used.

The near field extends from the last maximum (y^{o+}) pressure point to the transducer face.

The far field extends outward from the last peak of the energy pattern. The axial positions of the maxima (y^+) and minima (y^-) for plane circular piezo-electric element can be described by the equations:

$$y^+ = \frac{4a^2 - \lambda^2(2m+1)^2}{4\lambda(2m+1)} \qquad \text{where } m = 0,1,2,3 \ldots \qquad (5)$$

$$y^- = \frac{a^2 - \lambda^2 m^2}{2m\lambda} \qquad \text{where } m = 1,2,3 \ldots \qquad (6)$$

where y^+ = position of maxima along the central axis

y^- = position of minima along the central axis

a = radius of the piezo-electric element

λ = wavelength of sound in the considered medium.

As λ^2 is insignificant in water compared to the radius, the last peak where $m = 0$ in equation (5) reduces to:

$$y_o^+ = a^2/\lambda = \frac{d^2}{4\lambda} \qquad (7)$$

where d = piezo-electric element diameter.

As can be seen in Fig. 6, in the near field, the energy distribution is not homogeneous; on the contrary in the far field, the homogeneity is much better. It is therefore desirable to perform the ultrasonic inspection in this area, i.e. in the far field.

Table 4 indicates the calculated values, on the basis of equation (7) of the y_o^+ distance in mm, for some frequencies between 1 and 30 MHz and for piezo-electric element diameters from 1 to 32 mm.
The scaled line indicates the 20 λ limit. These calculated values are graphically represented in Fig. 7.

Diameter of the piezoelectric element (mm)

	1.0	2.25	4.0	5.0	6.0	10.0	12.0	15.0	20.0	30.0
1							2	2,5	3,4	5
2						6	8	10	13	20
3	$y_o^+ = \frac{d^2}{4\lambda}$		6	7	9	15	18	23	31	45
4			10	13	16	27	32	41	55	80
5			16	21	25	42	51	64	86	125
6		13	24	30	36	61	73	92	124	180
7		18	33	41	49	83	100	125	168	245
8		24	43	53	64	108	130	164	220	320
9		30	54	68	81	137	165	207	279	405
10	16	37	67	84	101	169	204	256	344	500
11	20	45	81	101	122	205	246	310	417	605
12	24	54	97	121	145	244	293	369	496	720
13	28	64	114	142	170	286	344	433	582	845
14	32	74	132	164	197	332	400	502	675	980
15	37	85	152	189	227	381	459	576	775	1125
16	42	96	172	215	258	433	522	656	882	1280
17	48	109	195	242	291	489	589	741	996	1445
18	54	122	218	272	327	549	661	830	1117	1620
19	60	136	243	303	364	611	736	925	1244	1805
20	67	151	270	336	404	677	816	1025	1379	2000
21	73	167	297	370	445	747	900	1130	1520	
22	81	183	327	406	488	820	987	1241	1668	
23	88	200	357	444	534	896	1079	1356	1824	
24	96	218	389	484	581	976	1175	1476	1986	
25	104	236	422	525	631	1059	1275	1602	2155	
26	113	256	456	568	682	1145	1379	1733	2331	
27	122	276	492	612	736	1235	1487	1869	2513	
28	131	296	529	658	791	1328	1600	2010	2703	
29	141	318	568	706	849	1425	1716	2156	2900	
30	151	340	608	756	909	1525	1836	2307	3103	
31	161	364	649	807	970	1628	1961	2464	3313	
32	171	387	691	860	1034	1735	2089	2625	3531	

Table 4 - Distance of the y_o^+ point in water.

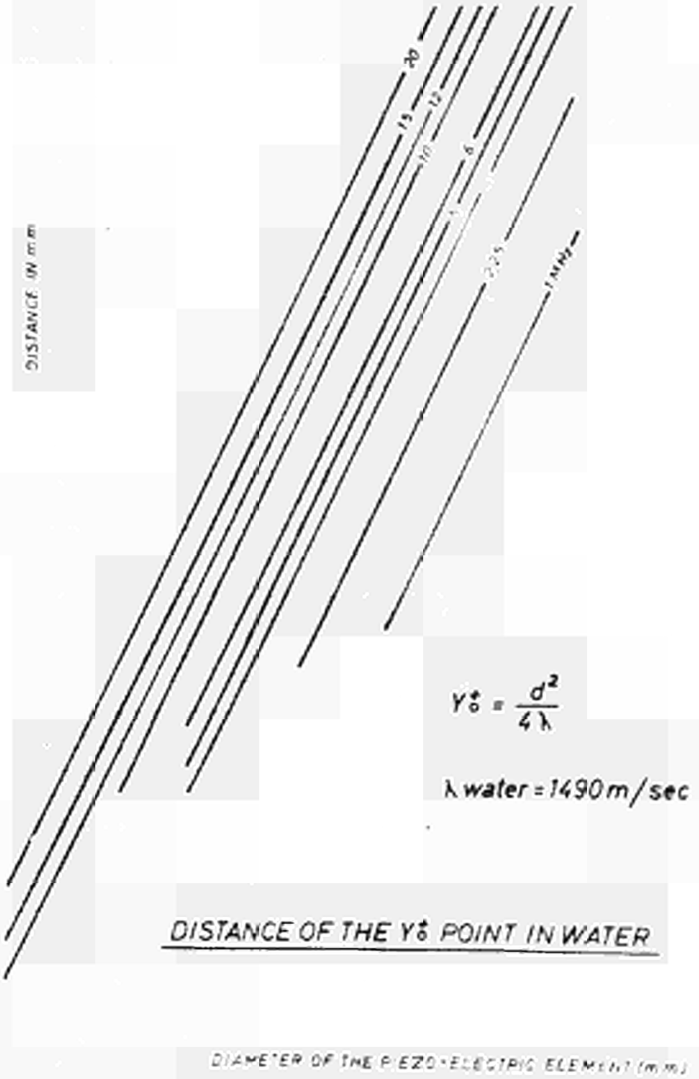


Fig. 7 - Distance of the y_o^+ point in water

5.3.3. Damping of the transducer

In order to obtain separate echoes from two inclusions, close to one another but at a slightly different distance, a high resolution transducer has to be used. In fact, the piezo-electric element must be returned to a completely quiescent state after having received the echo from the first inclusion before receiving the echo from the second inclusion. Constructively, the resolution of a transducer is enhanced by damping the piezo-electric element. This damping also enlarges the frequency spectrum of the transducer. In other words, high resolution transducers have a highly damped piezo-electric element and a large frequency spectrum (Broadband transducer).

5.3.4. Focused ultrasonic transducers

In order to obtain separate echoes from two inclusions, near each other and equi-distant from the transducer, a narrow ultrasonic beam must be used so that both inclusions are "seen" separately by the ultrasonic wave.

On the other hand, to obtain a maximal reflection, the inclusion should have the same dimension as the sound beam. For small inclusions (i.e. much smaller than the diameter of the piezo-electric element), both above mentioned conditions can only be fulfilled by using spherically focused transducers.

In fact, for flat transducers, we have seen in Fig. 7 that at high frequencies the y_o^+ distance in water is quite large and because of dispersion, the beam diameter is at least equal to the crystal diameter or even greater.

As described in Ref. 6 and 8, focusing of the ultrasonic beam is possible with the use of lenses. As the propagation velocity of ultrasonic waves is lower in water than in plastic materials, concave lenses made of araldite or perspex are used for focusing the sound beam. The two parameters characterizing the focusing of a transducer are: the diameter of the crystal and the radius of curvature of the lens.

Focusing a transducer always has the effect of reducing the y_o^+ distance and is only useful for immersion techniques.

Using focused transducers, the part of the sound beam to use is the focal zone i.e. the zone around the y_o^+ point as indicated in Fig. 8.

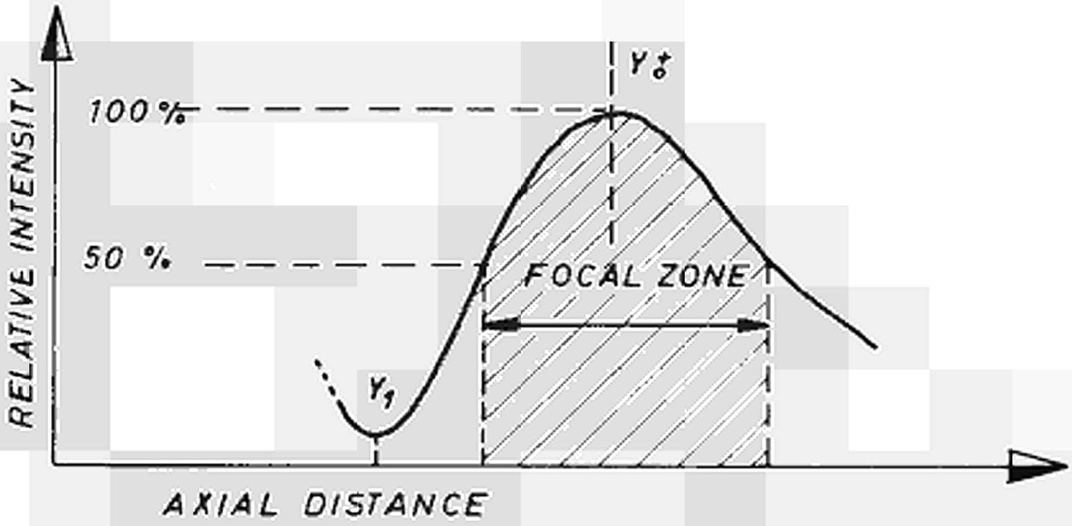


Fig. 8 - Axial pressure distribution of a focused transducer.

On the next figure (Fig. 9), the soundbeam of a spherical focused transducer is shown. The focal distance is defined as the length of the liquid column between the lens and the focal point y_o^+.

The focal zone is the distance between the two half amplitude points (Fig. 8) and the beam diameter at the focus is defined by the points where the amplitude drops to 1/10 of the maximal amplitude value.

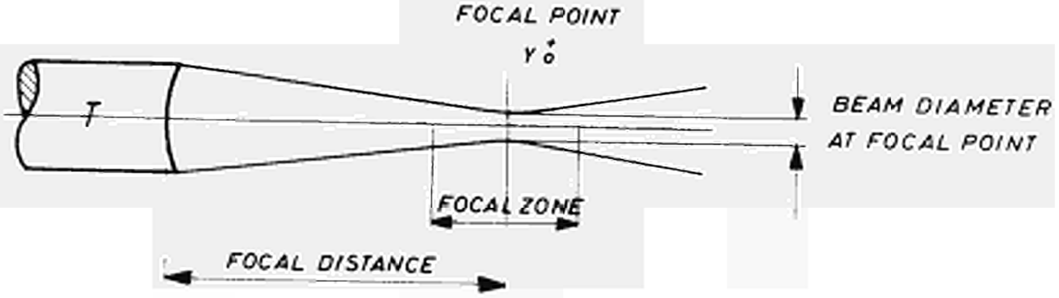


Fig. 9 - Soundbeam of a focused ultrasonic transducer.

5.3.5. Calibration of ultrasonic transducers

Ultrasonic transducers are basically manufactured using following components (Fig. 10). Piezo-electric crystal (a), damping material (b), housing (c), acoustic lens (d), matching transformer (e), connecting cable (f).

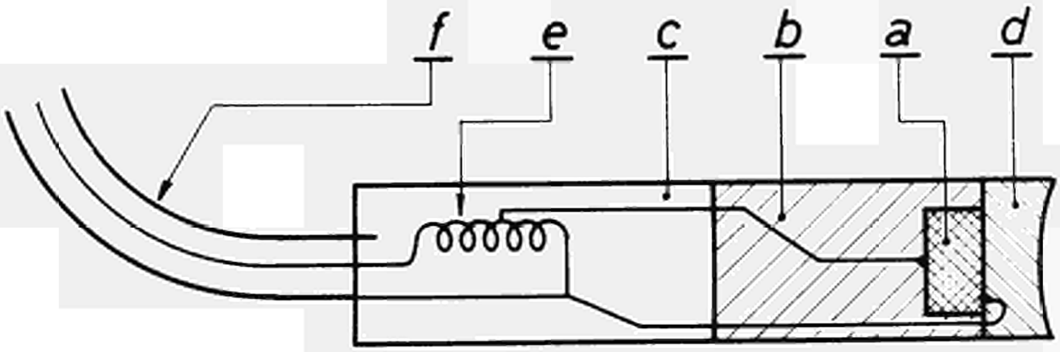


Fig. 10 - Components of an ultrasonic transducer.

Each of these components has its own characteristics and must respond to certain technological conditions in order to optimize the general characteristics of the transducer.

a) The piezo-electrical crystal: determines the basic frequency of the transducer. It has a metallization on both sides for applying the electric excitation pulse.

b) The damping material is an absorbing material which ipedes the sound-wave propagating into the transducer to be reflected and to come back **to** the crystal. This damping can be of different kinds and determines the bandwidth of the transducer. A highly damped one is a broadband transducer.

c) The housing contains all the components and must be water tight for immersion transducers.

d) Acoustic lens. This lens adjusts the focal distance of the transducer at a convenient distance.

e) The matching transformer adapts in a certain manner the impedance of the generator to the impedance of the used piezo-electric material. In certain types of transducers, this transformer can be omitted.

f) The connection cable must be electrically adapted to the transducer and also to the generator. When long cables are to be used, the adaptation of this cable becomes more and more critical.

Some examples of change in characteristics due to the components are given hereafter and their effect versus a reference transducer is mentioned:

- crystal frequency is different: results in a different resonant frequency, a displacement of the whole frequency spectrum, a variation of the beam characteristics due to the different ratio of wavelength to diameter of the transducer,
- damping element (backing) is different: results in a wider or a narrower frequency spectrum,
- crystal to lens bonding is imperfect: results in a considerable modification of the soundpressure of the emitted beam,
- crystal to backing bonding is imperfect: results in a considerable modification of the frequency spectrum,
- other lens characteristics: result in a modification of the sound beam (focal distance, beam diameter...)
- excentricity of the crystal in its housing : produces a misalignment of the mechanical and the acoustical axis of the transducer,
- crystal not mounted perpendicularly to the mechanical axis of the housing: results in an important misalignment of the mechanical and acoustical axis.

Due to the great number of parameters having a more or less important effect on the transducer characteristics, it is easy to understand that it is quite impossible to produce series of transducers with exactly the same electrical and acoustical characteristics. It is therefore necessary, when highly reproduceable results are required, to measure out all possible parameters of the transducers and afterwards to select those transducers having as near as possible equal characteristics.

All the above-mentionned characteristics can actually be measured either by electrical or by sound beam profile measurements. Some existing differences can be electronically compensated.
Others, such as sound beam misalignment can only be corrected by making use of calibration equipment in which the transducer is fixed in an intermediate ring after having corrected the existing lack of alignment (Fig. 11) on a reference reflector.

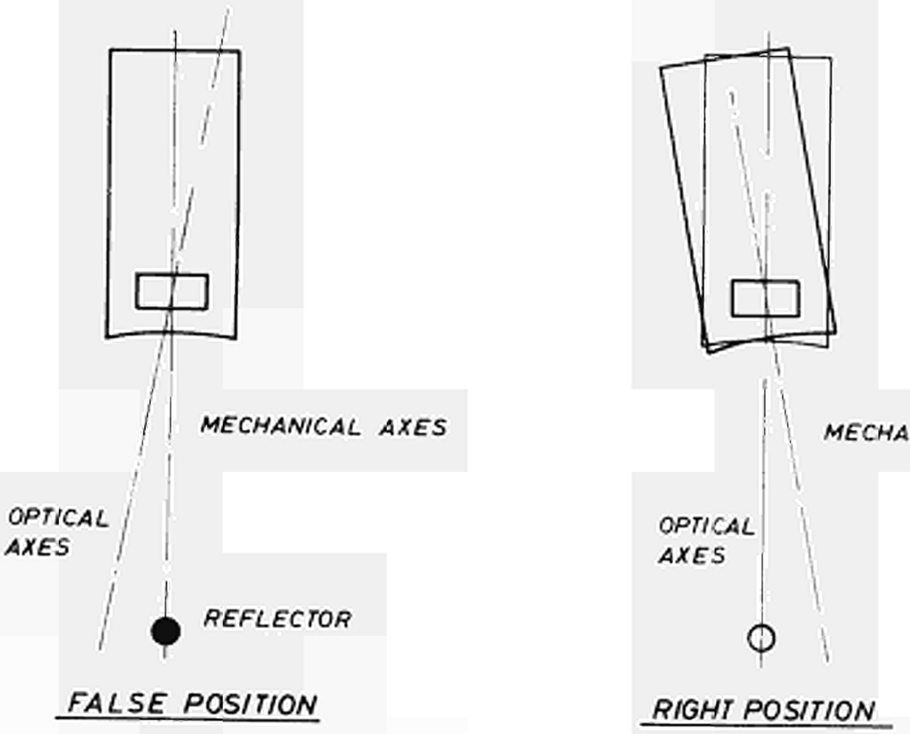
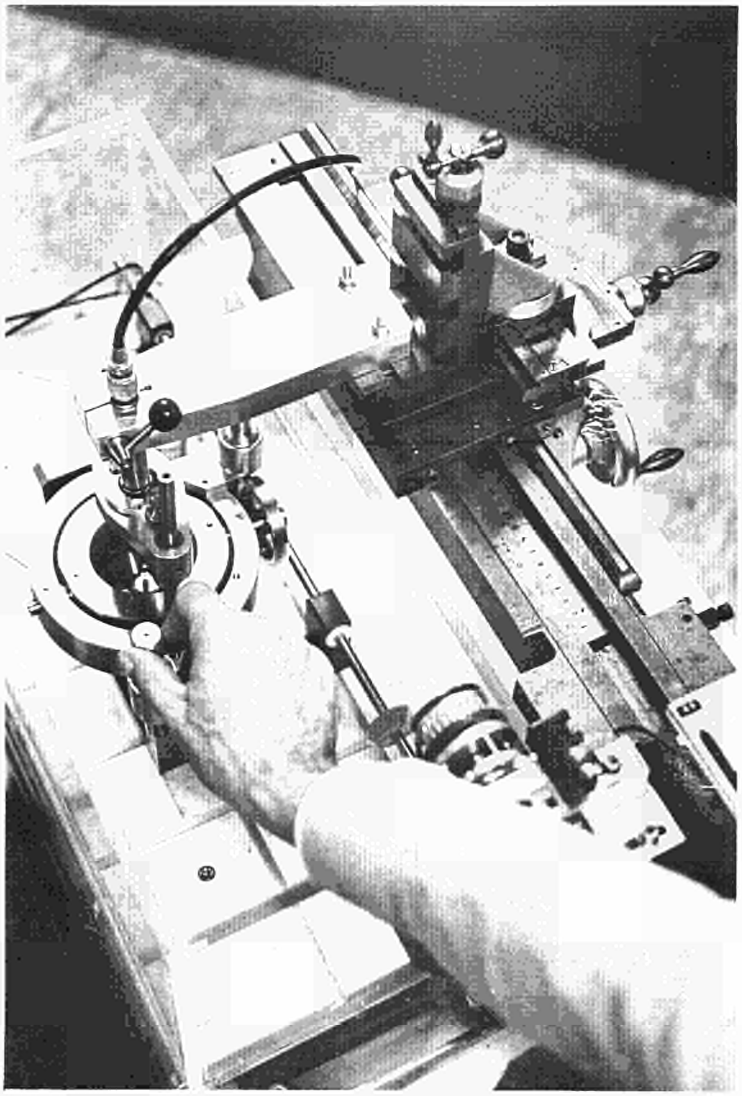


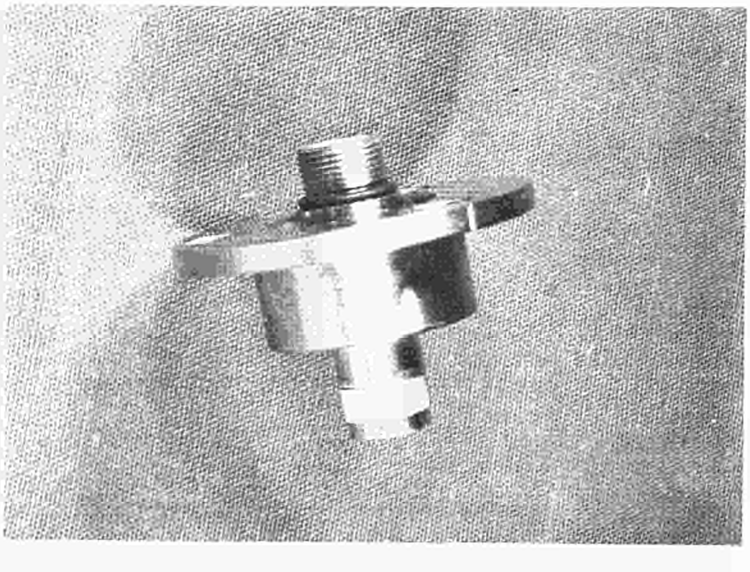
Fig. 11 - Correction of the misalignment of an ultrasonic transducer.



This same equipment also permits correction of the eventual difference in focal ditance. Our current calibration equipment is illustrated in Fig. 12. Fig. 13 is a picture of the centered transducer.

Fig. 12 - Misalignment calibration equipment.

Fig. 13 - Transducer mounted in the standard centering device.



6. DEAD ZONE

We have seen in § 5.1 that when an ultrasonic wave propagates in a medium Z_1 and enters in a medium Z_2, a part of the incident wave is reflected. When using the immersion technique the first medium is generally water. The second medium, according to the identification purpose, is plexiglass, aluminium, or stainless steel.

Considering the reflection coefficients of Table 1 for these different media, we find:

water - plexiglass	: 37%
water - aluminium	: 84%
water - stainless steel	: 93%

This important quantity of reflected energy at the interface produces the "entry echo" visible on the screen of the ultrasonic instrument. The width of this echo is proportional to the reflection coefficient and produces a more or less large "dead zone" which impedes reflections from near surface inclusions.

7. PRACTICAL CASES OF IDENTIFICATION WITH ARTIFICIAL MARKS

7.1. Identification of MTR type fuel element plate

The method developed at the J.R.C. Ispra for ultrasonic identification of MTR fuel plates consists in printing inside the plate, during the fabrication process and in the non active zone, some inclusions which can be detected ultrasonic by scanning of the edge of the place. Ref. (9), (10). MTR fuel element plates are sandwich elements made by rolling of three superposed aluminium plates, the central one being a frame into which the enriched fuel core is fitted (Fig. 14).

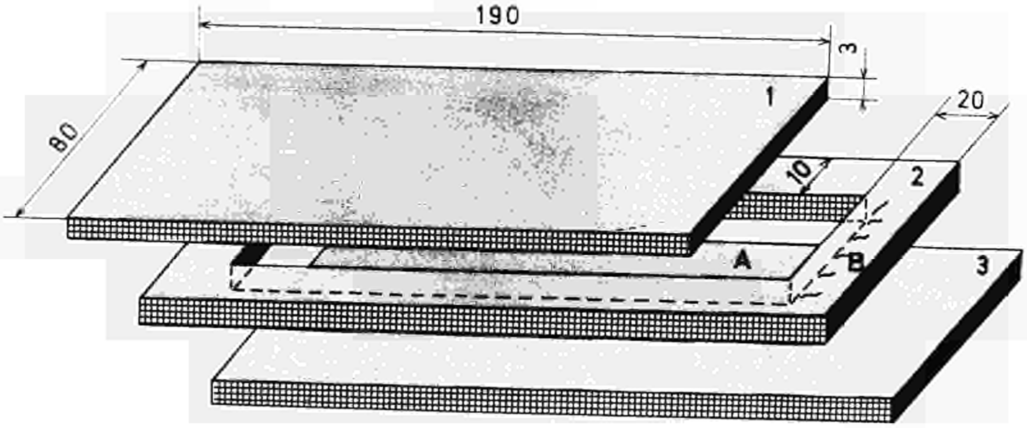


Fig. 14 - Initial sandwich for the fabrication of MTR plates.

The zone marked B on Fig. 14 will be used to give an identity to the fuel plate. Before initiating the rolling process some inclusions of foreign material (tungsten) are introduced into this zone. During the rolling phase, these inclusions are printed into the material and take random positions in the upper non active part of the plate (Fig. 15).

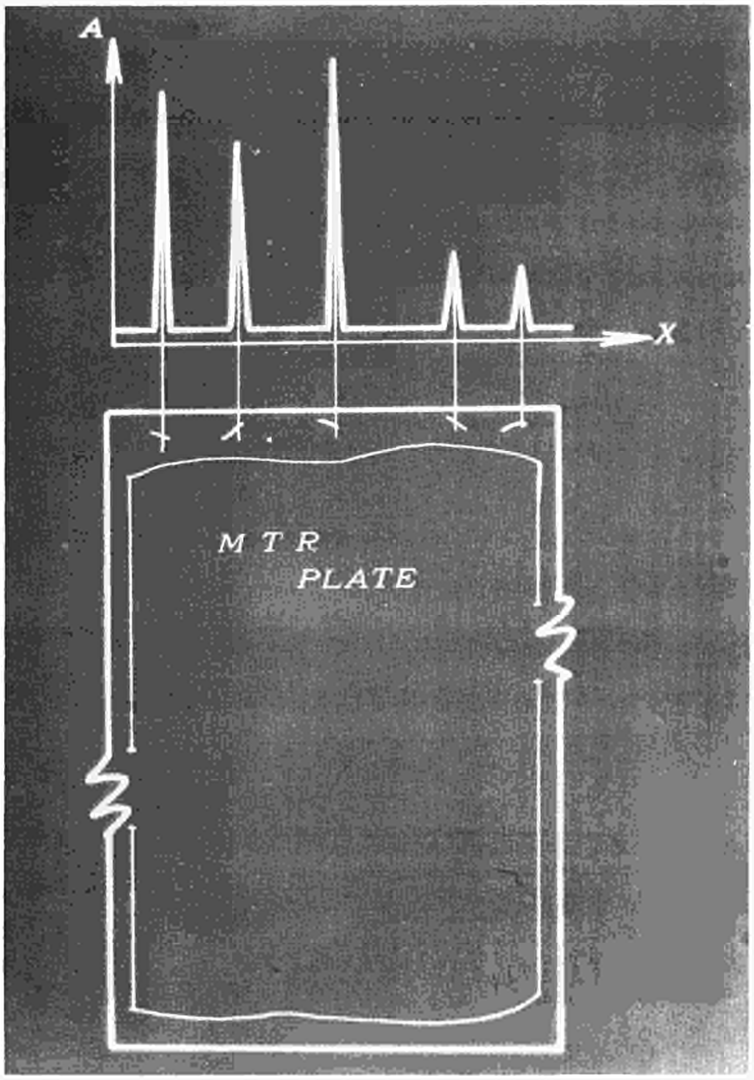


Fig. 15 - Positioning of the artificial marks in an MTR plate.

To read the ultrasonic identity of such an MTR plate, an ultrasonic transducer is set up perpendicularly to the edge of the plate in such a manner that the pressure wave penetrates into the MTR plate. A mechanical scanning along the edge reveals echoes on the ultrasonic instrument each time the transducer passes in front of an inclusion (Fig. 15).

These echoes are selected by means of the electronic gate of the ultrasonic apparatus and sent on to an analog recorder. The analog information (identity) can easily, if necessary, be transformed into digital information. In order to insure good and reproduceable coupling conditions between the transducer and the MTR plate, the measurement is made using water as couplant.

The practical tests made in our laboratory have given very good results. The method may be considered highly useful for identifying single fuel plates.

If, on the other hand, the identity measurement has to be performed on a mounted MTR fuel bundle, the mechanical scanning becomes so complicated that yet another identification method has been developed (rivet seal, see further) Ref. (13) (14).

7.2. The use of seals for identification purposes

7.2.1. Types of seals

As it is not always either possible or desirable to put artificial inclusions in materials which have to be protected by a tamperproof identification (or signature), the J.R.C. Ispra developed a series of seals having an inherent signature and which can be used when no natural marks are available Ref.(9) (10) (13) (14).

Basically three types of seals have been realized:

- "general use" seals, for sealing containers, doors, etc... which are already used by the Safeguard Directorate of Luxemburg,
- LWR or "cap" seals used for the identification of LWR fuel bundles,
- MTR or "rivet" seals used for the identification of MTR fuel elements.

All these seals can be identified in all environmental conditions (air, water, irradiation and temperature) using the same principle and an electronic portable or static apparatus; only the mechanical scanning has to be adapted to each type of seal.

7.2.2. Fabrication

The general characteristics for the fabrication of marked seals were already described in the report of Ref. (13). The main characteristics of the seals (composition, geometrical forms, types of inclusions) depend on their practical applications.

Different methods, using the powder metallurgy techniques have been set up for different types of seals:

- with a light matrix (plexiglass, aluminium, SAP) containing inclusions (bronze, tungsten, etc...)
- with a heavy matrix (stainless steel) containing inclusions (tungsten) or without inclusions but identified by their own particular structure.

7.2.3. Instrumentation for identity measurement with ultrasonics

The complete identification system is composed of three basic elements: a mechanical exploration mechanism, an ultrasonic instrument and a recorder (Fig. 16).

The mechanical exploration mechanism has to position the transducer very precisely and on the other hand to rotate the seal regularly around its mechanical axis. The mechanical tolerances of the transducer positioning system Ref. (15) and the difference in characteristics of various transducers of the same type and fabrication serial, can be defined (§ 5.3.5.) after a parametrical study to be performed for each application case.

The ultrasonic instrument.

Using a standard industrial ultrasonic apparatus, very satisfactory results were obtained as was shown by the parametrical study. Anyway, in order to increase the quality of the results, some modifications were made to the commercial instruments to render the position of the electronic gate highly reproduceable.
For measurements on the spot, a portable apparatus is currently under

development (for the IAEA). This apparatus is completely antonomous, and is also provided with an automatic calibration device. A digital output is optionally obtainable.

The recorder.

The registration of the electrical output signals is made in analog form. Most pen or photographic recorders can be used. The readout obtained is easy to interpret and may be integrally or partially used as an identity card (or signature). This analog information can be coded into a digital form for automatic storage and checking.

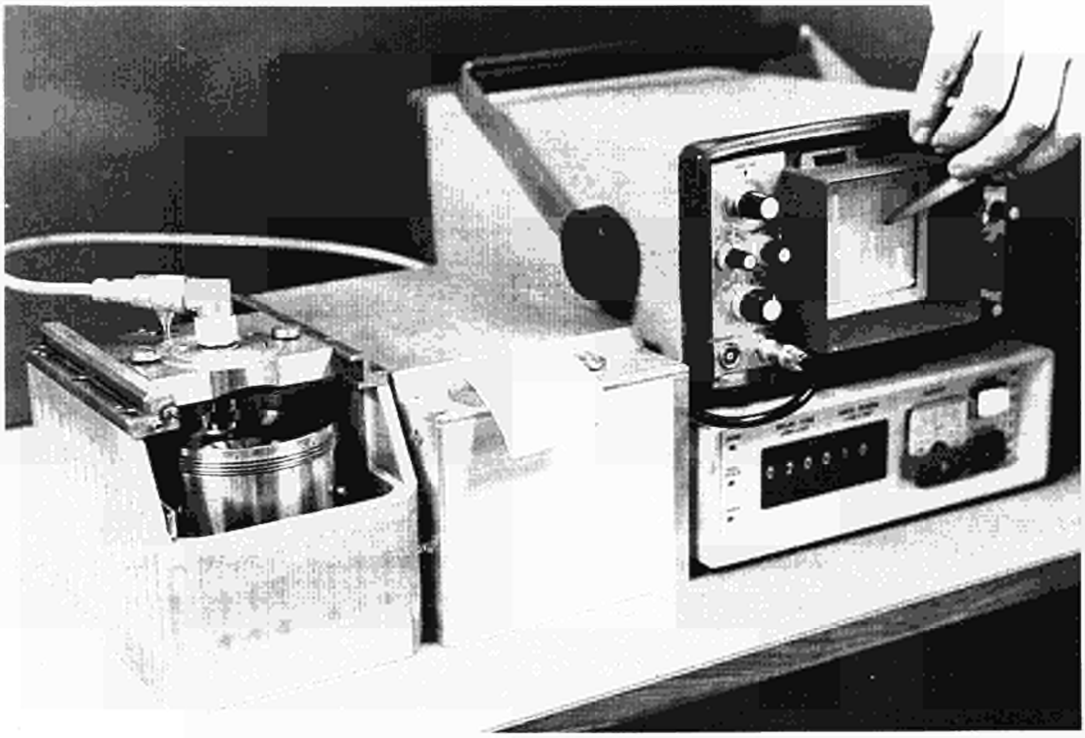


Fig. 16 - Example of a complete identification chain

7.2.4. General use seals

The general use seals are composed of a box and a cap, both made of sintered material (plastics, aluminium composites, stainless steel) containing metallic inclusions randomly dispersed.

These seals are to be used with tamperproof wires. The seal is closed by simply pressing the two parts together, an internal retaining ring providing an irreversible closure. Reopening is impossible without destroying the internal marking, which completely surrounds the locking system. (Fig. 17 and 18).

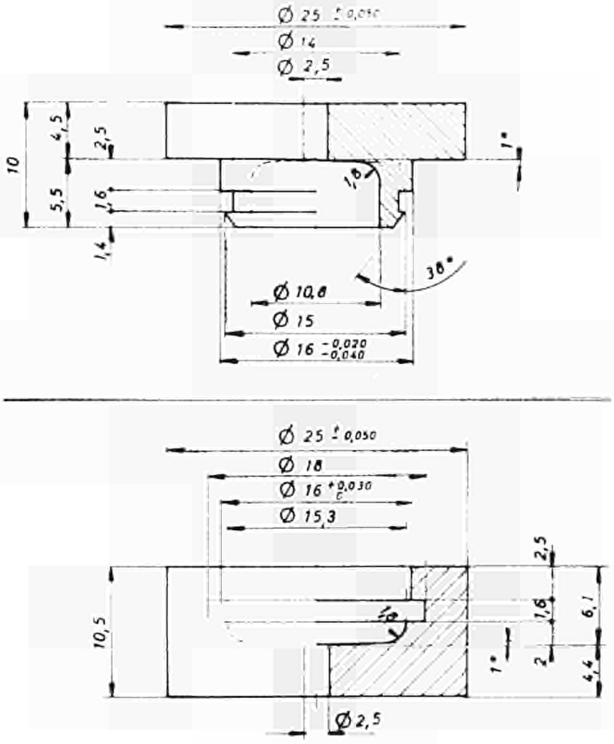


Fig. 17 - General use seal

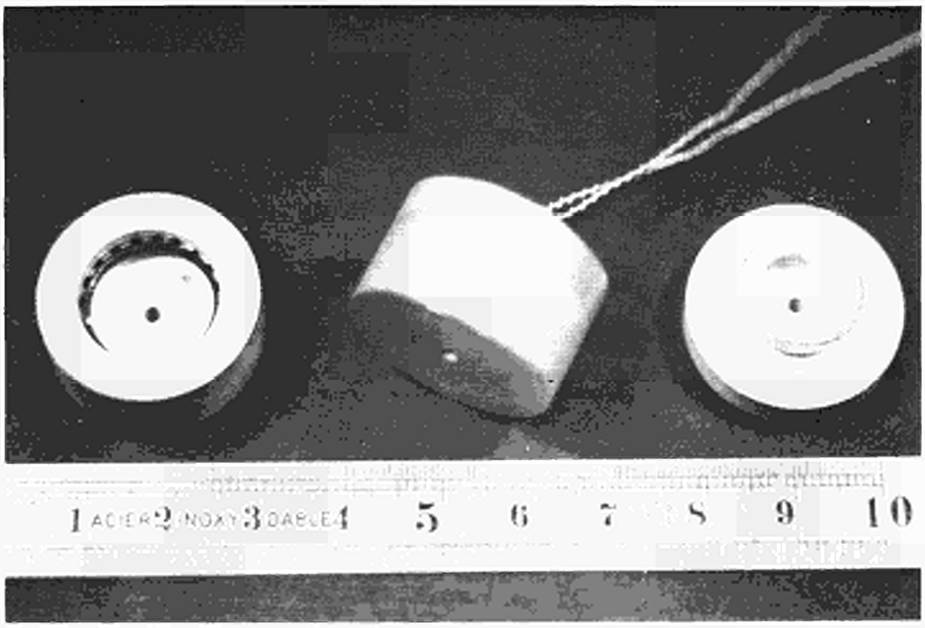


Fig. 18 - General use seal, open and closed showing the tamperproof wire.

The ultrasonic scanning must be made in such a way that any tampering tentative results in a change of the ultrasonic identification signals. Therefore, this type of seal must be scanned in four different places as indicated on Fig. 19.
The radial exploration reads the identity or signature of the seal, the axial exploration is either, an integrity control.

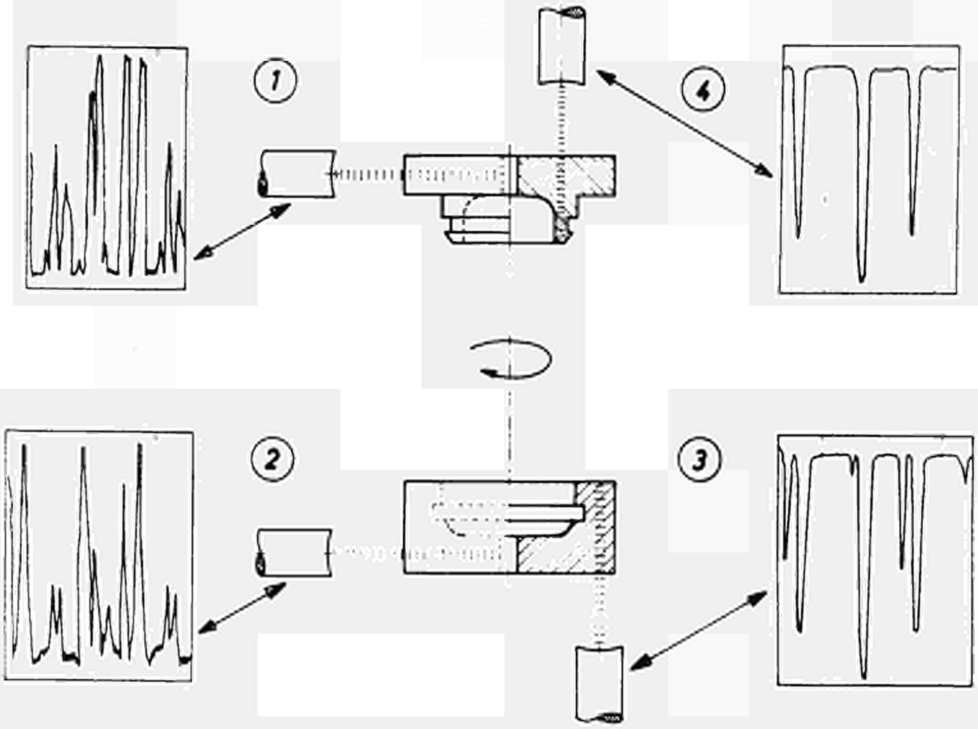


Fig. 19 - Ultrasonic scanning path for general use seal with an example of the documents obtained for each scanning.

Radial exploration: Positioning the seal in the exploration mechanism, the only mechanical adjustment to make is to place the transducer at the correct position for making the radial exploration. This position is of course pre-defined on the exploration mechanism and is the same for the cap or the box part of the general use seal. This being made, the rotational movement may be switched on.

On the screen of the ultrasonic instruments if the gain setting is correct, an image as represented in Fig. 20 is displayed when four inclusions, a, b, c, d are in the ultrasonic path.
To have the correct gain setting, the installation is calibrated either on an artificial standard defect or on an inclusion of the seal. Generally, the

second method is used. Therefore, the display is observed during one rotation of the seal and the maximal obtained amplitude (from an inclusion) is set to correspond to a reference value, f. i. 80% or 100% of screen amplitude. The portable apparatus is provided with an automatic calibration device.

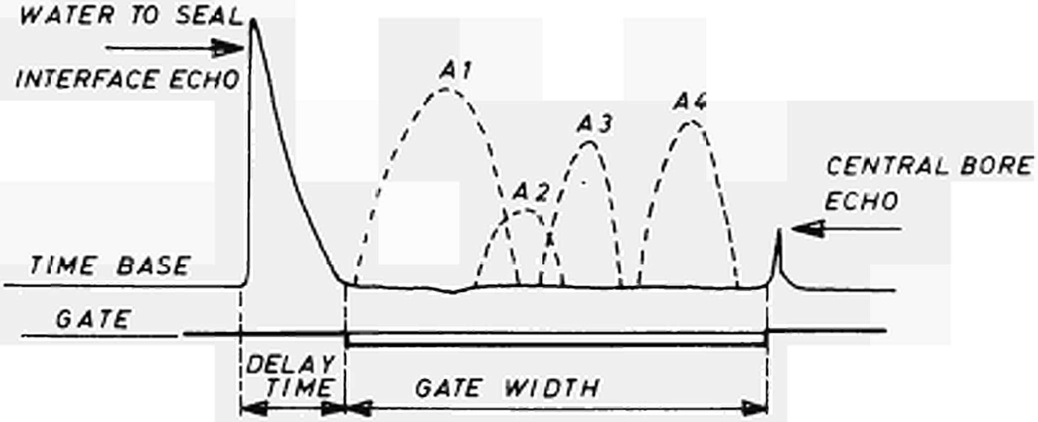


Fig. 20 - Display on the screen of the ultrasonic instrument.

In order to transfer to the recorder only those informations due to inclusions, we must select out of the time base the zone between the water to seal interface echo and the central bore echo (Fig. 20). This is made by the electronic gating circuit. This circuit normally exists in most of the commercially available instruments but the start point and the width of the gate are adjusted by potentiometers and are not precise enough when highly reproduceable results must be obtained. In order to avoid these drawbacks, a digital gate was developed at the J.R.C. Ispra. This gate driven by a 20 MHz clock, is synchronized with the front face of the water to seal interface echo.

Three digits determine the "delay time" and three other digits determine the gate width as indicated in Fig. 20. The digital gate apparatus can be seen on Fig. 16.

All the information appearing in the gate is transmitted through to the recorder but in such a manner that only the maximal amplitude, over the whole gate width, is memorized and recorded. To make this phenomenon clearer, let us consider as examples following possibilies:

- only information A_1 is seen on the screen, i.e. that A_2 A_3 and A_4 are positioned at other angular positions in the seal. In this case, the maximal analogue value transmitted to the recorder will correspond to the maximal value of the A_1 envelope shown in Fig; 20,
- if A_1 is seen at the same moment as A_2, for example, this means that the inclusions A_1 and A_2 are near one to another in the seal and are explored at the same moment by the sound beam.
  In this case, only the maximal value of A_1 will be recorded,
- if during the rotation of the seal the amplitude of A_1 decreases while the amplitude of A_2 increases, the signal applied to the recorder will decrease until the amplitude of A_1 and A_2 are at the same level, then the recorder signal will increase again following the amplitude variation of A_2.
  An example of an identification document is shown in Fig. 21.

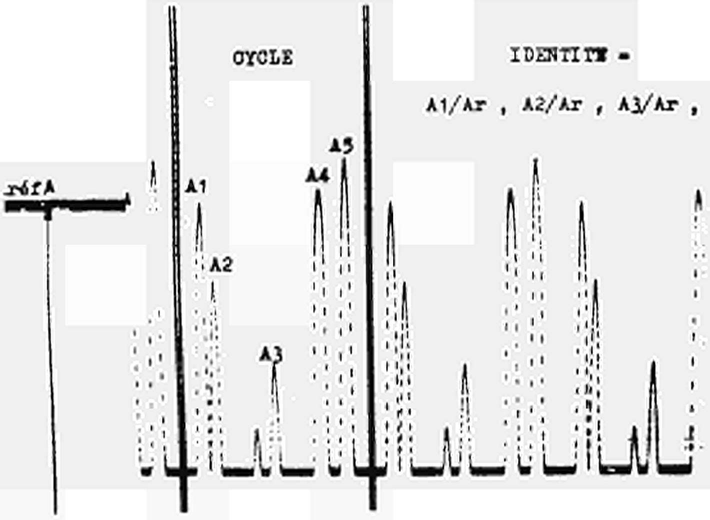


Fig. 21 - Identity of a seal.

In order to illustrate the great importance of precise gate setting, let us consider two particular conditions:

- due to the drift of the gating circuit, the entire gate shifts to the left in such a manner that a part of the entrance echo is permanently inside the gate (e.g. 50% amplitude). This results in a shift of the base line of the identification document to 50% amplutude when no inclusions are "seen" by the transducer. Only these inclusions producing echoes higher than 50% will modulate this base line. It is clear that under these conditions, the original identity is completely modified.
- due to the drift of the gating circuit, the gate width decreases. Here the base line remains in its normal position but the information due to inclusions whose echo is now outside of the gate is lost. The identity obtained is here also modified.

The digital gating circuit developed at J.R.C. Ispra eliminates these dangers as the circuit is completely drift free.

Axial exploration : The axial exploration must be considered more as an integrity control than an identity check. This measurement should principally reveal that the seal has not been tampered . Therefore, once more, the gate positioning is very critical: i.e. for the box part of the seal, the gate width must be set in such a manner that the end of the gate is as near as possible to the "end echo" of the seal (Fig. 22a)

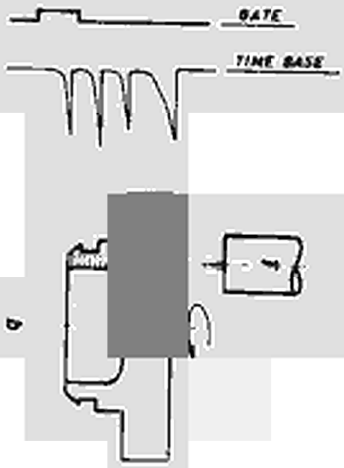


Fig. 22 a - [redacted]oning for the box part of a seal.
b - Gate positioning for the cap part of a seal.

For this measurement, it is not absolutely imperative to have information from inclusions. We then obtain a document with zero information. If the seal has been tampered the level at which it must break is the zone of the notch in which the retainer ring is fixed. When testing the box in these broken conditions, an important echo (the new "end echo") will appear in the gate and reveal tampering. If on the other hand, the broken part is glued into its original position, the glue, being a medium with a different acoustic impedance, produces an echo which also appears inside the gate and indicates tampering.

For axial exploration of the cap part of the seal, the principle is the same as that for the box part i.e. the sound beam must penetrate the leg as shown in Fig. 22b and the "end echo" must be visible. As this leg is very narrow, a fixed echo appears in correspondance with the upper edge of the notch. This fixed echo impedes the positioning of the gate in the same way as for the box. In this case, the solution retained is to monitor the amplitude of the "end echo". The gate is therefore set in such a way that it covers only this "end echo" (Fig. 22b). The gain setting of the instrumentation is increased in order to bring the amplitude of the back echo to 100%. The recorder document will now indicate, when no inclusions interrupt the sound beam, a constant level at 100%. Eventual inclusions cause a momentary decrease of this 100% amplitude line.

Constructively, this part of the seal is dimensioned so that, when a tampering attempt occurs, the lower part of the leg breaks at the level of the retainer ring notch. The ultrasonic scanning of the broken leg produces an "end echo" out of the gate and no more information exists inside the gate. The original 100% information changes into a zero information and clearly indicates tampering.

Note: The gate setting for monitoring the "end echo" amplitude can also be used for the box part of the seal as shown in Fig. 19.

7.2.5. Cap seals

This type of seal was designed for the identification of light water reactor fuel elements. The seal is a cap made of stainless steel which, following the general principle, contains randomly distributed inclusions. Its configuration is shown in Fig. 23.

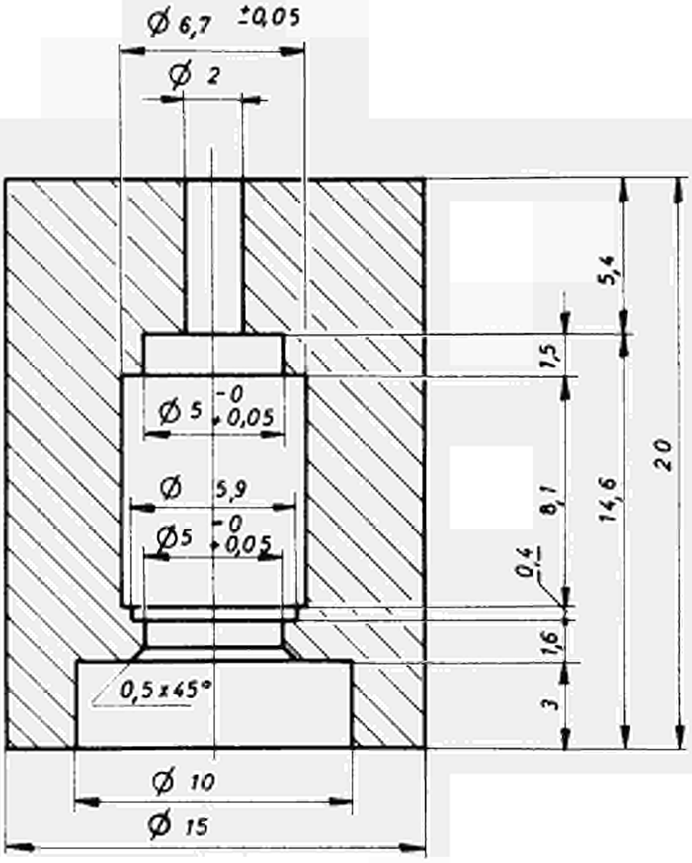


Fig. 23 - Cap seal.

For identification purposes, here also, two ultrasonic scannings have to be performed. Contrary to the general use seal, the identification is performed scanning in the axial direction and the integrity control, scanning in the radial sense.

Fig. 24 shows the scanning modes for a cap seal. The gate setting for the identity measurement is made in the same way as the radial exploration of a general use seal i.e. the gate starts immediately after the interface echo and stops just before the bottom echo.

For the integrity control the gate is set on the echo due to the central bore, in order to monitor the echo amplitude as for the axial exploration of the general use seal. Both obtained documents are represented in Fig. 24.

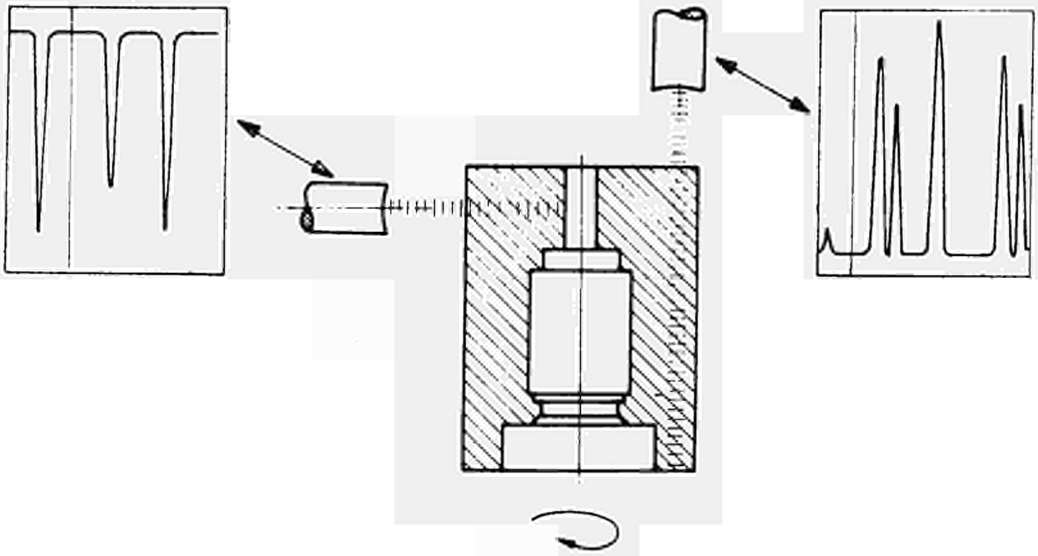


Fig. 24 - Ultrasonic scanning mode for cap seals.

For this type of seal, a special mechanical scanning device has been developed permitting the identification of a seal mounted on the LWR fuel element, placed in the cooling pool of the reactor. For identification, the exploration mechanism may be at a distance of 10 to 30 meters from the electronic instrumentation.

For this particular case, special care has been taken to match the impedances of the transducer, the cable and the instrumentation. The use of a special pulser, made in our laboratories, has given really satisfactory results.

7.2.6. Rivet seal

As shown in Fig. 25, the seal is composed of a disc into which the inclusions are inserted, and a cylindrical foot used for positioning.

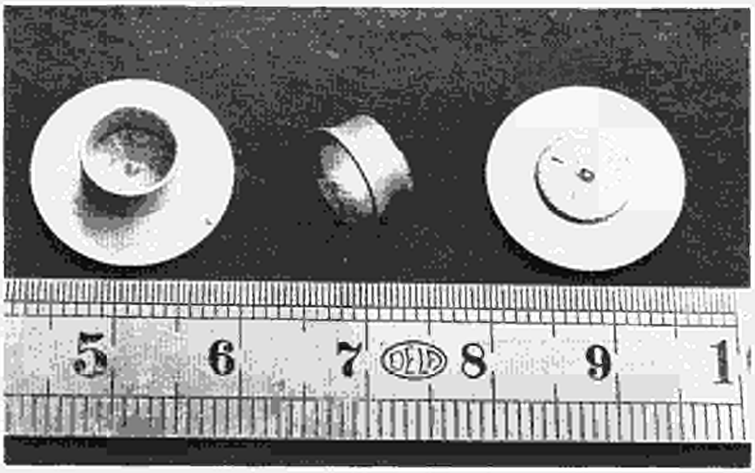


Fig. 25 - Rivet seal, left : before mounting, right : broken

The mechanical dimensions of this type of seal are rather small, an example is given in Fig. 26.

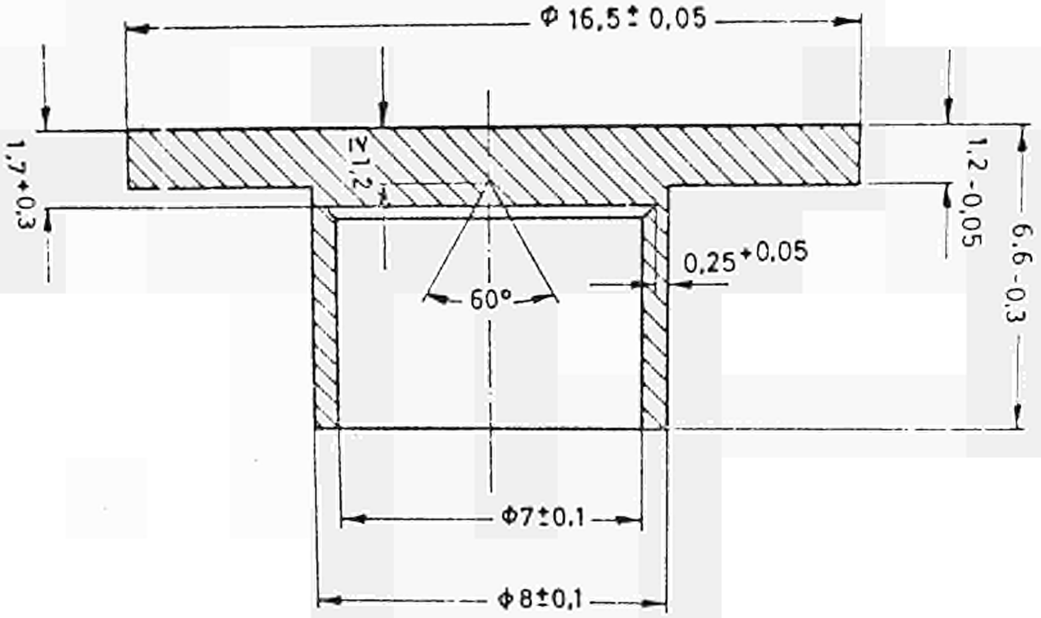


Fig. 26 - Dimensions and tolerances of a rivet seal.

This type of seal is the most complicated to identify ultrasonically. The ultrasonic beam must enter into the edge of the seal; due to the thinness, a highly focused transducer must be used and be positioned very precisely.

The principle of the ultrasonic identification measurement is shown in Fig. 27.

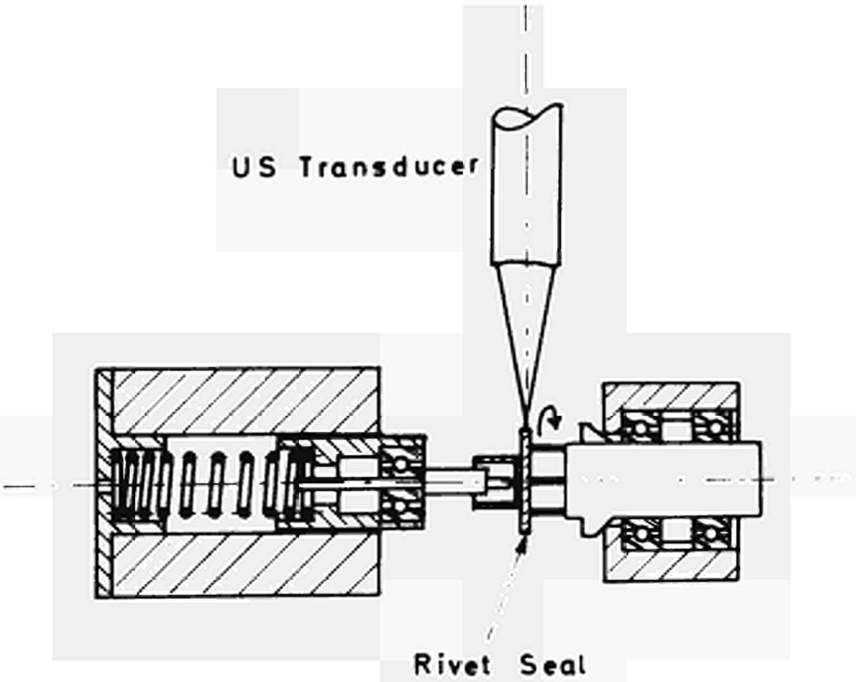


Fig. 27 - Rivet seal scanning device.

As for the other types of seals, the installation is calibrated either on an artificial standard or on an inclusion of the seal.

The ultrasonic wave entering the rivet seal is, as in the other cases, reflected on the artificial inclusions but here, due to the small size of the seal, the wave is also reflected against the walls and other inclusions in such a way that much more information is obtained than the true quantity of inclusions present in the seal.

The gate setting can be normal : i.e. start just after the end of the entrance echo and stop at a distance corresponding to the central zone of the seal. In many cases, it will be more convenient, in order to obtain a less complicated identification document, to select a much narrower gate. Even in these conditions, due to the internal reflections (scattering), the identity informations are modulated by the inclusions which are not in the gated zone. The tamper proofness of the seal is then maintained.

An example of an identification document is shown in Fig. 28.

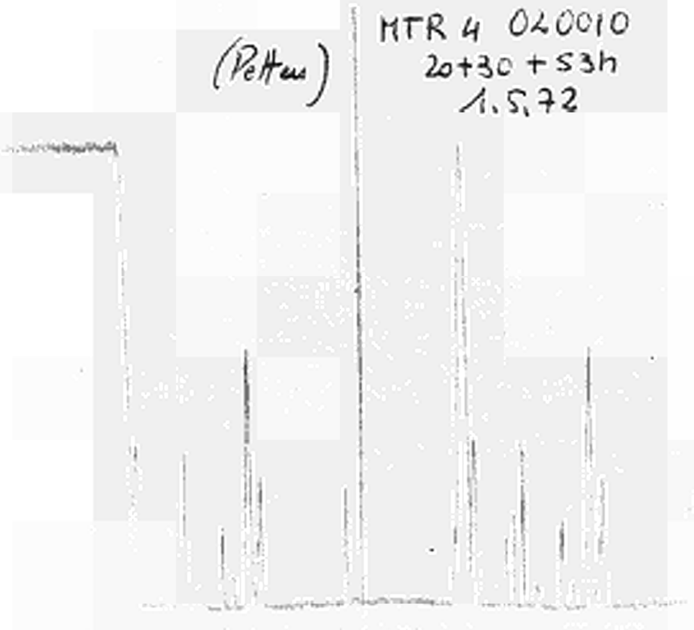


Fig. 28 - Identity document of a rivet seal.

8. GENERAL CONSIDERATIONS ON THE IDENTIFICATION CHAIN

In order to simplify the operation procedure, the instrumentation must be as universal as possible. Different types of seals made of different basic materials are to be considered. From the mechanical point of view, the exploration mechanism for "general use" seals can also explore cap seals. Only for rivet seals another mechanical scanning system is needed.

Up to the present time the different materials used are: plexiglass with bronze inclusions, sintered aluminium powder (SAP) with tungsten inclusions and stainless steel with tungsten inclusions.

Referring to paragraph 5, a great many factors must be taken into account in order to optimize the testing conditions for each type of seal. Our aim has been to define practically the constructive parameters and the testing parameters in such a way that the fewest possible interchangeable parts need to be used when passing from one type of seal to another. In practice, we could find experimentally one single transducer able to measure out the identity of all the above-described seals.

Of course, measurement conditions such as: gain setting, mechanical positioning of the transducer, gate setting, are different for each type of seal but these settings are basically defined in our laboratories.

In the portable prototype at present under development, the identity measurement will be still further simplified. The most important changing parameters are: suppression of the display on a cathode ray tube, automatic gain setting and simplification of the identity document due to the use of a new type of recorder developed for this purpose in our laboratories. Optionally, a digital output can be incorporated.

9. DATA TREATMENT

As can be seen from the scheme of Fig. 29, various alternatives can be considered for the data treatment.

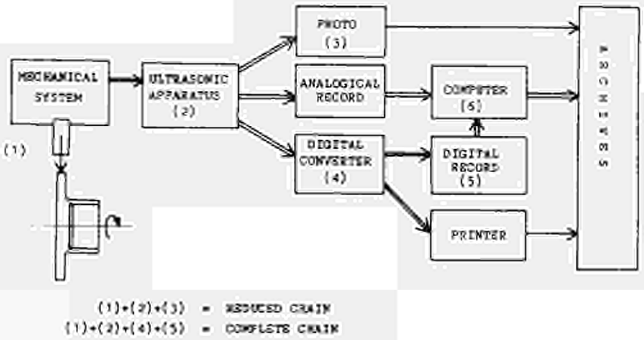


Fig. 29 - Data treatment possibilities

The reduced chain, composed of blocks (1), (2) and (3) makes no use of a recorder. The identity document is obtained by making a photograph of the screen of the ultrasonic instrument.

A second possibility is to make an analogical recording of the identity. This analog information is sent into a computer for data treatment.

A third possibility is to transform the analog information emitted by the ultrasonic instrument into digital information by means of the digitalizer (4). The output of the digitalizer is connected to a digital printer and also to a computer compatible digital recorder (5).

10. CONCLUSION

All the different types of seals developed up to now in our laboratories can, using the same basic principle, be identified ultrasonically.

The obtained signature can be a photograph or an item of analog or digital information.

For further applications other seals can be developed, always using the same principle. The identification conditions must be defined for each individual type in a laboratory.

Remote identification can be performed but somewhat more sophisticated circuits are recommended.

REFERENCES:

(1) J.H Krautkrâner
"Ultrasonic Testing of Materials"
Springer-Verlag-Berlin-Heidelberg-New York 1969.

(2) P. Biquard
"Les ultrasons"
Collection : Que sais-je. Presses Universitaires de France.

(3) E.E. Borloo
"An Ultrasonic Technique for the Inspection of Magnetic and Explosive Welds, Using a Facsimile Recording System".
Non-Destructive Testing - February 1973 - p.25-28.

(4) F. Laghi; F. Merli
"Table of Reflection Coefficients"
To be published J.R.C. Ispra.

(6) G.J. Posakony - R.C. Mc Master
"The Analysis of Focused Ultrasonic Test Techniques "T.P. N^{o}601
Automation Industries

(7) J.T. Mc Elroy
"Ultrasonic Search Units"
T.R. 67.4 -1967
Automation Industries Inc.

(8) J.T. Mc Elroy
"Focused Ultrasonic Beams"
TR 66.40-1966 - Automation Industries Inc.

(9) P.S. Jehenson, S.J. Crutzen, E.E. Borloo, J.C. Jansen
"Procedés d'identification à preuve de fraude en vue du contrôle de la circulation des matières fissiles par la technique du containment".
IAEA Symposium SM 133/26 - Karlsruhe - July 1970.

(10) P. Jehenson, S. Crutzen
"Identification Techniques in the Control of Fissile Materials"
Eur. 4842 e - Annual report 1971.

(11) S. Crutzen, J. Faure, M. Warnery
"System for marking of objects, in particular fuel elements in nuclear reactors"
Euratom patent; United Kingdom N° 1241.287, 10 July 1969

(12) W. Bürgers, S. Crutzen, J. Jansen, P. Jehenson
"Improvements in Tamper-Resistant Sealing Systems"
Euratom Patent, United Kingdom, N° 1278-749; 16 June 1970.

(13) P. Jehenson, S. Crutzen
"Identification Techniques in Safeguards"
Eur 5107.e - to be issued - JRC Ispra 1973.

(14) S. Crutzen, P. Jehenson, E. Borloo, W. Buersers
"A rivet seal for Safeguarding the MTR Fuel Element"
Eur 5110.e - J.R.C. Ispra 1973 (to be issued)

(15) S. Crutzen, E. Borloo
"Uncertainties and Tamper-Resistance of an Ultrasonic Signature"
Eur. 5109 e (to be issued) J.R.C. Ispra 1973.

(16) S. Crutzen and P. Jehenson
"Surveillance and Containment Technique Symposium on Practical Aspects of R and D in the Field of Safeguards" - Rome, March 1974.
by the European Safeguards R and D Assoc. E.S.ARDA.

NOTICE TO THE READER

All scientific and technical reports published by the Commission of the European Communities are announced in the monthly periodical **"euro-abstracts"**. For subscription (1 year: B.Fr 1 025,—) or free specimen copies please write to:

Office for Official Publications
of the European Communities
Boîte postale 1003
Luxembourg
(Grand-Duchy of Luxembourg)

> To disseminate knowledge is to disseminate prosperity — I mean general prosperity and not individual riches — and with prosperity disappears the greater part of the evil which is our heritage from darker times.
>
> Alfred Nobel

SALES OFFICES

The Office for Official Publications sells all documents published by the Commission of the European Communities at the addresses listed below, at the price given on cover. When ordering, specify clearly the exact reference and the title of the document.

UNITED KINGDOM

H.M. Stationery Office
P.O. Box 569
London S.E. 1 – Tel. 01-928 6977, ext. 365

BELGIUM

Moniteur belge — Belgisch Staatsblad
Rue de Louvain 40-42 — Leuvenseweg 40-42
1000 Bruxelles — 1000 Brussel — Tel. 512 00 26
CCP 50-80 — Postgiro 50-80

Agency :
Librairie européenne — Europese Boekhandel
Rue de la Loi 244 — Wetstraat 244
1049 Bruxelles – 1049 Brussel

DENMARK

J.H. Schultz — Boghandel
Møntergade 19
DK 1116 København K — Tel. 14 11 95

FRANCE

Service de vente en France des publications
des Communautés européennes — Journal officiel
26, rue Desaix — 75 732 Paris - Cédex 15ᵉ
Tel. (1) 306 51 00 — CCP Paris 23-96

GERMANY (FR)

Verlag Bundesanzeiger
5 Köln 1 — Postfach 108 006
Tel. (0221) 21 03 48
Telex: Anzeiger Bonn 08 882 595
Postscheckkonto 834 00 Köln

GRAND DUCHY OF LUXEMBOURG

Office for Official Publications
of the European Communities
Boîte postale 1003 — Luxembourg
Tel. 49 00 81 – CCP 191-90
Compte courant bancaire: BIL 8-109/6003/300

IRELAND

Stationery Office — The Controller
Beggar's Bush
Dublin 4 — Tel. 6 54 01

ITALY

Libreria dello Stato
Piazza G. Verdi 10
00198 Roma — Tel. (6) 85 08
CCP 1/2640

NETHERLANDS

Staatsdrukkerij- en uitgeverijbedrijf
Christoffel Plantijnstraat
's-Gravenhage — Tel. (070) 81 45 11
Postgiro 42 53 00

UNITED STATES OF AMERICA

European Community Information Service
2100 M Street, N.W.
Suite 707
Washington D.C. 20 037 — Tel. 296 51 31

SWITZERLAND

Librairie Payot
6, rue Grenus
1211 Genève — Tel. 31 89 50
CCP 12-236 Genève

SWEDEN

Librairie C.E. Fritze
2 Fredsgatan
Stockholm 16
Post Giro 193, Bank Giro 73/4015

SPAIN

Libreria Mundi-Prensa
Castello 37
Madrid 1 — Tel. 275 51 31

OTHER COUNTRIES

Office for Official Publications
of the European Communities
Boîte postale 1003 — Luxembourg
Tel. 49 00 81 – CCP 191-90
Compte courant bancaire: BIL 8-109/6003/300

OFFICE FOR OFFICIAL PUBLICATIONS OF THE EUROPEAN COMMUNITIES
Boîte postale 1003 – Luxembourg 6692

CDNA05108ENC