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NON-DESTRUCTIVE TESTING OF URANIUM SLUGS: SUMMARY REPORT THROUGH MAY 1953

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UNITED STATES ATOMIC ENERGY COMMISSION
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NON-DESTRUCTIVE TESTING
OF URANIUM SLUGS
SUMMARY REPORT THROUGH

MAY 1953

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ABSTRACT

This report summarizes the major activities in non-destructive testing of uranium slugs supported by the New York Operations Office over the past year and a half, with references to detailed reports where they exist. Test methods are described for the detection of cracks, inclusions, and striations in bare slugs by eddy currents and ultrasonics, the determination of grain size and crystal orientation by vibration techniques, and the detection of unbonded regions in canned fuel elements.

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I. BACKGROUND OF TESTING PROGRAM

Interest in non-destructive testing of fuel elements was motivated at NYOO in November, 1951 by the Hanford experiences. Up to that time, there had been comparatively little Commission activity in this field. Some work had been done with the Sperry ultrasonic Reflectoscope and the General Electric Metals Comparator, an eddy current type instrument, at Hanford by Frank Quinlan and Richard Sockey and with the Magnetic Analysis Equipment by H. L. Hull and F. Digney at Argonne. At that time, the work at these sites had not progressed to the point of a useful technique and NYOO chose to start again from scratch.

In December, 1951, several alpha rolled bare uranium slugs were taken to the Naval Research Laboratory where the Reflectoscope and another ultrasonic instrument, the General Motors Sonigage, were available for exploratory tests. The Reflectoscope, which locates internal flaws by "radar like" reflection of ultra high frequency sound showed up sawcuts and holes that had been drilled into the slugs but failed to indicate the presence of any natural flaws, if there were any. The Sonigage, which sets up standing resonance waves in the metal and can therefore be used for highly accurate thickness determinations, failed to respond in an interpretable way even to the man-made defects. However, the pattern on the screen of the Sonigage was found to rise and fall as the slug was rotated about its axis while the vibrating quartz crystal of the instrument was held against the side of the slug. This effect is shown in Figure 1, which is a record of the Sonigage response

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at intervals of 10° around the circumference of a slug. When it appeared that maxima always occurred at 90° intervals in slugs that had been rolled with a 90° turn between rollings, Contract AT(30-1)-1344 was placed with the Naval Research Laboratory to investigate the application of sonic and ultrasonic techniques to the study of preferred orientation in slugs. This work was under the direction of Dr. Irwin Vigness and demonstrated that not only ultrasonic but sonic flexural vibration responded to orientation, as described in reports NYO-3787 and NYO-3575. More recently, activities under this contract have turned toward studies of the elastic constants, expansion coefficients, and internal damping of uranium slugs especially as a function of temperature (see report NYO-6212).

Also in December, 1951, NYOO purchased the Cyclograph (developed by Du Mont) and began to study the effects of cracks, seams, and laps in bare slugs and also penetrations in canned slugs on eddy currents induced in the slug. Figure 2 shows the response of the Cyclograph (again on a cathode ray screen) to can defects. Results interested Argonne where the object was to develop methods for can inspection, and Argonne has since modified and further developed the Cyclograph method into a finished inspection tool for the detection of also penetrations into the can wall. No further eddy current work on canned slugs was done by NYOO.

In January, 1952, NYOO learned of a new group of eddy current test instruments recently developed by F. Förster at the Kaiser Wilhelm

Institute for Metallurgy in Stuttgart, Germany. By giving a two dimensional impedance analysis, the Förster equipment (Figure 3) not only responded to variations in the slug but identified whether they were diameter variations, resistivity variations, or deep, shallow, narrow, or wide cracks (see Figure 4 and reports NYO-3576 and NYO-3577.) Inasmuch as lack of identification was the drawback of the Cyclograph and the G. E. Metals Comparator, NYOO subsequently devoted its efforts to the Förster equipment. Several instruments were supplied to NYOO by the Magnaflux Corporation, Förster's U. S. representatives, where they had just been received on loan from Förster and were under preliminary study. In July, 1952, the writer visited Förster in Germany (reports NYO-3577 and NYO-3580) and during the same month, when the studies outgrew the limited facilities of NYOO, Sylvania Electric Products Co., Bayside, New York, was contracted to carry out the development of the new methods. Sylvania was chosen for reasons of proximity, excellent laboratory facilities, and because this project contributed to and would be assisted by their powder metallurgy activities for the Commission.

An unusually close liaison was maintained between Sylvania and the NYOO Research Division over the past year with frequent planning meetings between the two groups and visits by the writer who participated in some of the development activities.

Tests were made in February, 1952 with the Sonigage and the Reflectoscope to determine whether grain size (especially transformation) differences might be detectable ultrasonically in uranium slugs without

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resort to metallographic examination. The results of preliminary tests, which included two samples of fine grain Sylvania powder metallurgy slugs, are shown in Figure 5. A modification of this technique is now used by Sylvania to non-destructively test all powder metallurgy slugs for the presence of transformation. A purchase order type contract was subsequently negotiated with Sperry Products, Inc. (manufacturers of the Reflectoscope) to further study the applications of the Reflectoscope to slug inspection. H. E. Van Valkenburg directed this study.

In March, 1952, an attempt was made to determine whether the ultrasonic methods might replace the frost test for the detection of unbondings in canned slugs. Figures 6 through 11 show the responses of the Sonigage and Reflectoscope to good and poor bonds. (This technique was not pursued by NYOO but has been developed into two different types of automatic inspection equipment by groups at Hanford under E. C. Wood and Argonne under H. L. Hull.)

Förster visited NYOO in October, 1952, and we discussed with him certain problems regarding difficulties we had had in testing for and identifying very small cracks and other defects approaching microscopic dimensions in bars. Supported by his own research funds, and chiefly for his own purposes, Förster developed a new instrument (a revised version of his Defectometer) over the Winter and Spring of 1953 which he claims solves these difficulties. The instrument has just been received by NYOO but had not been tested at the time of this writing. Förster claims that it can determine both the depth and character of a flaw.

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FIGURE 1.

RESPONSE OF SONIGAGE
WHEN SLUG IS ROTATED

FIGURE 2 - CYCLOGRAPH RESPONSE TO CAN DEFECTS

a) sound can

b) slight penetration

c) deep penetration

FIGURE 3
FORSTER
MULTITEST
EQUIPMENT

FIGURE 4 - RESPONSE OF MULTITEST
TO VARIOUS TYPES OF FLAWS

a

b

Motion of Dot on Multitest Screen for:

a. seam

b. deep crack

c. diameter variation

d. resistivity variation

FIGURE 5 - ULTRASONIC GRAIN SIZE SIDDLES ON FIVE VARIOUSLY PREPARED HANFORD SLUGS

Frequency range 3

Frequency range 5

SLUG HELD AT 720° C
FOR 7 MINUTES,
AIR COOLED.

SLUG HELD AT 720° C
FOR 70 SECONDS,
WATER QUENCHED

REGULAR ALPHA
ROLLED SLUG

SYLVANIA POWDER

U SLUG

Grain size: 10 - 15
microns

SYLVANIA POWDER

UH₃ SLUG

Grain size: 5 - 10
microns

ULTRASONIC BOND TESTS

Good Bond

RESONANCE METHOD (Sonigage)

Fig. 6 Well bonded
beta canned
slug.

Fig. 7 Well bonded
alpha canned
slug.

Lack of Bond

Fig. 8 Alpha or beta canned
slug showing lack of
bond.

REFLECTION METHOD (Reflectoscope)

Fig. 9 Well bonded
beta canned
slug.

Fig. 10 Well bonded
alpha canned
slug.

Fig. 11 Alpha or beta canned
slug showing lack
of bond.

Since December, 1952, attempts have been made to find a technique for measuring internal stresses in slugs under thermal stress conditions. A discussion of this work has been omitted from this report but may be found in report NYO-6212.

There has also been interest in a modified type of test reactor for determinations of the neutron absorbing impurity content or reactivity of slugs, ingot samples, and oxide samples. This reactor is described in a separate report, NYO-6166.

II. OBJECT OF TESTING PROGRAM

When in November, 1951, the NYOO Research Division initiated a program aimed at the development of non-destructive test methods for uranium slugs, bars, and ingots, the object was to develop methods for detecting flaws or conditions that potentially might lead to pile failure. Little was known and little still is known about what flaws and inhomogeneities might actually be responsible. Thus the object was rather to develop methods of examining slugs, bars, or ingots inside and out for any inhomogeneities regardless of their conjectured influence on pile behavior.

This approach is destined for trouble because it will be asked what conditions shall slugs, bars, or ingots be rejected for? It is relatively easy to place specifications on exterior dimensions and visual surface inspection because the variables are only skin deep. But when the eye is replaced by a transmitter and receiver of ultrasonic energy or of

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magnetic energy or of x-rays it is found that one or the other of these basically different methods will detect some inhomogeneity which might just as readily cause trouble in almost every piece tested. Obviously one cannot reject 95% of production. The recourse is to re-examine the criteria on which fuel element specifications are based in the light of the new tests.

The object of the work at NYOO has been to supply information for such a re-examination. Until the present time we have spent relatively little time on developing automatic testing and sorting mechanisms. We have instead attempted a search for methods that will give information about the structural characteristics of slugs, bars, and ingots. In particular, eddy currents have been studied to determine if they may be used to analyze the sub-surface character of flaws in bare slugs; ultrasonics has been used in the study of orientation, grain size, inclusions, and bond soundness.

Attention was given to the question of what region in a slug was to receive the major emphasis in testing. It was decided that the outer 1/8" shell was the most important, then the surface only, the interior sections, and the center in decreasing order of priority.

One criterion in the choice and development of methods has been the ability of the method to free the test from inspector interpretation. A test that responds to half a dozen variables has little value if it does not identify the variables, because a single set of specifications

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will hardly do for the whole group. Especially in eddy current testing, interpretation continues to be a major problem. It is being attacked in two ways. On the one hand, sectioning and metallographic analysis is being carried on for correlation with the eddy current results. Secondly, attention has been given to coil design and phase sensitive electronics that will differentiate between various kinds of effects.

The object of future activities will be to stress more heavily the development and engineering of production line tools and the accumulation of data (correlated with metallographic results) on larger numbers of samples.

III. DETECTION OF CRACKS AND STRIATIONS IN BARE SLUGS BY EDDY CURRENTS

Figure 12 shows the laboratory setup currently being used at Sylvania for the detection of small cracks in bare uranium slugs. The slug is mounted in a lathe and rotated as an eddy current coil system (inside the box surrounding the slug) moves slowly in a horizontal direction. The coil system, dubbed the "orthogonal probe", has been operated at frequencies up to 100 Kc and employs two very small probe coils at opposite sides of the slug surrounded by a large coil which encircles the slug and sets up a magnetic field perpendicular to the probes. The probes do not detect this field as long as it is perpendicular to their mutual axis. However, when the field is distorted, as it is even by a small crack, the probes receive a signal which is filtered and amplified (by electronics not shown) and fed into a Brush pen recorder. The system was developed by H. Holloway and associates at Sylvania.

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The pen is shown as it makes a record on a paper cylinder which rotates in unison with the slug. The paper may then be unrolled and examined.

Figure 13 shows a slug magnified about 3-1/2 times with a typical crack about 3/16" long. Figure 14 is the corresponding pen trace, magnified about 2-1/2 times. This display method is not original but was used previously by General Electric. Figure 15 shows a single crack. The trace corresponding to this slug, Figure 16, shows three major field distortions. One of these may be attributed to a crack on the other side of the slug. The other was found on subsequent sectioning to reveal a flaw below the surface and invisible when the test was made.

The ability to detect sub-surface flaws is one of the important features of eddy current testing. Sensitivity to sub-surface flaws may be controlled by choice of test frequency. Another advantage of this method is that it lends itself to automatic inspection and sorting by relays that kick slugs out of line whenever the signal exceeds a certain magnitude.

Besides metallographic examination, "button" tests, in which 2" sections of slugs are compressed axially under about 100,000 to 150,000 psi, have been made to correlate with the electronic data. These tests show that areas picked out as faulty by the eddy current methods often tend to propagate stresses and crack open into deep crevasses under severe axial compression.

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Fig. 12

Fig. 13

19

Fig. 14 - (x 2-1/2).

Fig. 15

21

Fig. 16

Figure 16 shows also what appear to be several ridges, resembling "mountain ranges" on contour maps, that run over part or the entire length of the slug pattern. The origin of these ridges is still in doubt. It was presumed that they were orientation effects, though they were more pronounced than should be expected with a probe system of the type used. Etching with nitric acid has suggested that at least the smaller ridges may actually correspond to local accumulations of sub-surface striations within the slug, because these shorter ridges move around and change character each time the slug is etched another few mils. The longer ridges appear to remain fixed in position and are presumably the effects of surface orientation.

IV. ELECTRONIC INTERPRETATION OF EDDY CURRENT DATA

The importance of identifying the separate effects, such as orientation, striations, and cracks, to which eddy currents respond has been mentioned earlier. There are at least two ways to assist identification. One is coil design and the other is to measure the phase as well as the magnitude of the magnetic field responsible for the signal. For instance, it would probably be possible to minimize or eliminate orientation effects by placing two probes side by side in the longitudinal direction on the slug and measuring the difference of the voltage induced in each. Since orientation effects are quite constant in the longitudinal direction, the effect will cancel. However, cracks and striations which are short, irregular, and local, will be picked up as before. Therefore the coil design approach continues to obtain major emphasis at Sylvania.

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The second approach, that of phase sensitivity, has been utilized in the instruments produced by the Förster Institut in Reutlingen, Germany, which were reported on in NYO-3576 and NYO-3577. Two Multitests have been undergoing tests at Sylvania and a third instrument, the Förster Defectometer, has just arrived but has not yet undergone tests.

The Defectometer was developed by Förster in the Spring of 1953 with a view toward specific problems which we had discussed with him. It is likely also to find wide application in industry. It employs a single test probe which sets up its own magnetic field and measures the perturbations produced in it by flaws in the test piece, which may be either flat or have a curved surface. Förster reports that the instrument will detect microscopic flaws on and beneath the surface but is insensitive to motion of the probe away from the test piece, an effect that is so considerable in some instruments that small vibrations during test may obscure the data. This insensitivity to motion is accomplished by taking data at a certain phase of the signal in which the motion has no component.

With the Multitest, this same suppression of the probe-motion effect is possible but thereafter it is no longer possible to identify the cause of the signal. For this reason, Förster utilized in the new Defectometer the display principle of one of his other instruments, the Draht-Rissprüfgerät. The signal is displayed as a line or an ellipse on a cathode ray screen. By studying the angle of tilt of the line or major axis of the ellipse, and the eccentricity of the ellipse it is

possible to identify the nature of the disturbance, that is, whether it lies under the surface or in the surface and whether it is a conductivity variation (such as orientation) or a flaw. The response is instantaneous, permitting high scanning rates, and adjustment is comparatively simple. The new method, according to Förster, lends itself readily to automatic inspection. It is equipped with a red light that flashes when preset tolerances are exceeded.

Sylvania should be ready to report on this instrument in a few months.

V. INSPECTION FOR CRACKS AND INCLUSIONS BY ULTRASONICS

H. E. Van Valkenburg at Sperry Products, Inc. and N. Grossman at Sylvania, have applied the ultrasonic Reflectoscope method to the inspection of uranium slugs. The Reflectoscope is similar in principle to radar. High frequency sonic waves are sent through the material to be tested. On a fluorescent screen, pips are seen for the reflection of the sound from the front face, from the back face, and from any inclusions or discontinuities within the metal.

Figures 17, 18, and 19 show results obtained on three Sylvania powder slugs shooting longitudinally. Figure 17 is typical of most slugs. It shows only the front end reflection (left pip) and back end reflection (right pip). The line in between is broken by an electronic signal which rules off inches (note four inches from front to back reflection). Figure 18 shows an additional pip about 2-1/2" from the front end. Figure 19 shows an additional pip about 1" from the front end. These

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Fig. 17- good slug showing only front and back reflection.

Fig 18 - slug with discontinuity (arrow)

Fig. 19 - slug with discontinuity (arrow)

FIGURE 20 - GOOD SLUG

FIGURE 21 - SLUG WITH SEAM

ULTRASONIC ANGLE BEAM METHOD

FIGURE 22 - GOOD SLUG

FIGURE 23 - SLUG SHOWING PIPE

ULTRASONIC DIAMETER SHOTS

extra pipes originate from discontinuities within the metal and show up in the corresponding position when the signal direction is reversed.

Natural defects of this type have not been found in rolled slugs. However, artificial faults such as transverse and radial drill holes of small diameter have been readily detected. A method has also been developed to detect natural surface cracks by directing the ultrasonic beam circumferentially around the slug just beneath the slug surface (angle beam method). However, results of the latter method (shown in Figures 20 and 21) are difficult to interpret. So far eddy current methods show a clear advantage in detecting longitudinal surface flaws whereas ultrasonic methods appear to be more sensitive to internal inclusions and voids. Figures 22 and 23 show the detection of an axial test hole drilled to simulate pipe. Here the ultrasonic beam is directed along a diameter through the slug.

Tests with the Reflectoscope seem to indicate that flaws having a wide range of distribution and orientation could be detected in uranium bars provided they represented a reflecting interface equivalent to about .003 square inches.

VI. DETERMINATION OF GRAIN SIZE BY ULTRASONICS

In order to determine how Reflectoscope and Sonigage patterns were influenced by the grain size of the test sample, N. Grossman at Sylvania prepared ten samples of brass of carefully controlled grain size. The samples varied in grain size over a range of about 1 to 10,

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and were studied over a range of frequencies. A fairly sharp fade out of transmission (similar to that at the top of Figure 5) was found to occur when the wave length of the ultrasonic wave reached the order of magnitude of a grain diameter, that is, the fade out came at increasingly lower grain sizes as the ultrasonic frequency was increased. Brass was used because the grain size of this material can be controlled accurately.

The method was then applied to uranium and has since been used as a test of all Sylvania powder slugs. Some slugs have been found to show grain growth near the center, presumably due to overheating of the mold. An example is shown in Figure 24 taken with the Sonigage. The drawing at the top of the page represents the slug and shows the center transformed as indicated by metallographic studies. The photographs are of the signal on the screen of the Sonigage for the twelve positions indicated in the drawing. When the amplitude is high, as for position 1, the grains are small and ultrasonic transmission is good. When the amplitude is low, as for position 7, the grain size is large and on the order of magnitude of the wave length of the ultrasonic wave. This results in the scattering of most of the energy and the resultant decrease of the amplitude of the pattern.

The advantage of the ultrasonic test for grain size over metallography is its simplicity and speed. All that is required is that a small probe be touched to the surface. Readings are instantaneous and the entire volume of a slug can be scanned in a few seconds to determine if there has been transformation.

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VII. DETERMINATION OF CRYSTAL ORIENTATION IN SLUGS

It is known that the velocity of sound energy in a single crystal varies in the different crystal directions because it depends on the elastic properties of the crystal. Any inhomogeneity of structure in slugs which carries with it a similar pattern of elastic inhomogeneity, such as orientation, should therefore be expected to give rise to variations in ultrasonic velocities in various directions in a slug. Such variations have been studied with the Reflectoscope in alpha rolled slugs prior to beta heat treatment at the Naval Research Laboratory by I. Vigness, E. W. Kammer, S. D. Hart, and L. C. Cardinal under Contract AT(30-1)-1344, and are shown around a circumference of a slug in Figure 25.

As shown in Figure 1, ultrasonic attenuation is also markedly affected by this elastic anisotropy. The amplitude of the Sonigage pattern is a measure of ultrasonic transmission along the various slug diameters.

Further evidence of anisotropy was found by NRL in sonic flexural vibration experiments. As shown in Figures 26 and 27, the slug is mounted on fishlines and vibrated magnetically at sonic frequencies by means of a driver coil and magnetic transformer iron bands cemented around the ends of the slug. The frequency of the driver coil is tuned until the slug is in fundamental flexural resonance, then, with the frequency held fixed, the slug is rotated. The amplitude of vibration of the slug is measured by a pickup coil at the other end and the signal is fed through a high-gain amplifier into a vacuum tube voltmeter and an

Prepared by NRL

Figure 25 Polar diagram of pulse velocities for bar No. ABC-1-12.

Figure 26 SIMPLIFIED SKETCH OF SET-UP USED IN FLEXURAL MODE EXPERIMENTS ALSO SHOWN IS METHOD OF DETERMINING CORRELATION BETWEEN CIRCUMFERENTIAL REFERENCE NUMBERS AND BAR-NUMBER REFERENCE PLANE. (Prepared by NRL)

Fig. 27 - Photograph of flexural mode experiment.

(Prepared by NRL)

Figure 28 Polar plots of flexural amplitudes for bar No. 3077-B-20

(Prepared by NRL)

Figure 29 Polar plots of flexural amplitudes for bar No. ABC-1-12

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oscilloscope. A typical variation of the meter reading as the slug is rotated is shown in Figures 28 and 29 for two resonant frequencies. Note that there are actually two different resonant frequencies which attain their maximum along diameters 90° apart. The four arrows on each graph mark the positions along which the Sonigage pattern stood at a maximum.

It will be seen that Figures 25 and 29 represent the same slug. The lack of correlation between ultrasonic and sonic vibration insofar as direction is concerned may perhaps be attributed to the fact that flexural vibration is more sensitive to orientation near the surface, whereas ultrasonic vibrations is equally sensitive to effects along the entire diameter. Some slugs curiously showed no sonic anisotropy but did show marked ultrasonic anisotropy. This led to some fear that slight ellipticity of the bar might actually be responsible for the sonic results. Accordingly, calculations were made, and it was shown that the slight ellipticities which the bars did have were in no way sufficiently large to account for the observed effects.

Report No. NYO-3787 has been prepared by NRL and details the procedures used and data obtained in these experiments.

VIII. EXPLANATION OF FIGURES 6 THROUGH 11

Ultrasonic bond tests have not been carried beyond the exploratory stage at NYOO. Figures 6 through 11 were however, included in this report to show that ultrasonic methods do show considerable promise insofar as the detection of unbonded regions in canned fuel elements is concerned. The tests are described in principle below.

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A. BOND INSPECTION BY ULTRASONIC RESONANCE (SONIGAGE)

When the thickness of the material under test is an exact multiple of the ultrasonic wave length, a standing wave is set up and resonance occurs. This amounts to saying that for a given piece of material, as one tunes through a range of frequencies at constant energy supplied to the crystal, there will be sudden and considerable increases in the amplitude of vibration of the material whenever the signal wave-length is an integral fraction of the thickness of the piece. On a plot of amplitude of vibration versus frequency, pips occur for the fundamental and each harmonic frequency. Figure 8 shows the fundamental and first harmonic. Figure 7 covers the range from about the 150th to the 220th harmonic.

Actually the frequency ranges covered in the three figures is identical (about 2 to 3 megacycles). The differences arise because resonance characteristics depend on the thickness, grain size, and sound velocity in the material under test.

In each of the three figures, an ultrasonic wave was sent axially through a canned Hanford slug. Only the slug in Figure 8 was unbonded at the point of test. Figure 7 represents the vibration of a 4 inch thick piece of uranium bonded on both sides to a cladding of aluminum-alsi, whereas Figure 8 represents the vibration of a thin piece of aluminum-alsi alone, no energy being transmitted into the uranium due to lack of bond.

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Under close examination, Figure 6 also reveals the presence of minute resonance pips from about the 150th to 220th harmonic as in Figure 7. Bonding has nothing to do with the difference between Figures 6 and 7 since both slugs were well bonded. However, the slug in Figure 6 was beta heat treated during canning whereas the slug in Figure 7 was not and remained in the alpha rolled state. As was noted earlier, beta heat treatment increased the grain size in the uranium to the order of magnitude of the wave length of 2 to 3 megacycle waves in uranium. As the result, scattering predominates and the ultrasonic transmission characteristics of the metal are greatly reduced.

B. BOND INSPECTION BY ULTRASONIC REFLECTION (REFLECTOSCOPE)

When an ultrasonic wave traveling through matter encounters a boundary of any kind, part of the wave is transmitted across the boundary and part reflects back. The relative magnitude of the reflected wave depends upon the difference in acoustic properties of the materials on either side of the boundary.

In the case of metal-to-air boundary, virtually 100% of the energy is reflected, while for a water-to-aluminum boundary, 72% of the energy is reflected and 28% is transmitted into the aluminum. In the latter case, the transmitted wave will continue through the aluminum until it strikes the rear surface where it again undergoes the reflection-transmission phenomena. The reflected portion returns to the front surface where part of it is again reflected so that the

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wave continues to reverberate in the aluminum until all the energy is lost either by transmission through the front or back surface or by scattering in the aluminum.

Figure 11 shows about 40 such reverberations in the aluminum jacket of a canned slug at a point where there is lack of bond so that all of the energy remains in the can and none is transmitted into the uranium. On the other hand, Figure 9 and Figure 10 show only the first front face and back face reflections in a well bonded slug where the signal travels with negligible reflection at the bonds across the entire axial length of the slug and reflects off the far surface. The broken base line in Figures 9 and 10 is produced by an electronic signal which rules off inches in uranium. It will be noted that the reflection from the far surface in a beta heat treated canned slug is much smaller than the corresponding reflection in an alpha canned slug. The explanation is again, that attenuation is higher in beta transformed metal.

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