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NONDESTRUCTIVE TESTING
OF ISOTOPE CONTAINMENT CAPSULES:
SNAP-21 FINAL REPORT

June 1969

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NONDESTRUCTIVE TESTING OF ISOTOPE
CONTAINMENT CAPSULES: SNAP-21 FINAL REPORT

By

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CONTAINMENT CAPSULES: SNAP-21 FINAL REPORT

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April 1969

ABSTRACT

Because of the toxic and radioactive core material contained in the SNAP-21 isotope capsules, it is imperative that the container integrity be assured through a reliable quality control program. Remotely implementable ultrasonic weld inspection techniques and equipment were developed to provide nondestructive test quality assurance for the SNAP-21 closure welds. The SNAP-21 weld inspection test, when implemented with the UT-40 ultrasonic test station, automatically detects weld anomalies such as porosity, laminar voids, and unfused joint interfaces. The ultrasonic anomaly indications are recorded with an X-Y mapping technique which displays circumferential and axial anomaly locations in addition to anomaly axial length. The anomaly indications are interpreted through comparison with indications observed from 0.012 to 0.070 in. diameter standard reference surfaces.

This report is the formal presentation of the SNAP-21 ultrasonic weld inspection test technology. The test is based upon ultrasonic signals obtained by the helical scanning of the weld volume with an ultrasonic beam aligned normally incident on the capsule side. Both normally occurring and special case ultrasonic signals and their relationship to the weld characteristics are discussed. Alignment of the ultrasonic beam up to 3° from normal in the axial plane and signal wave shaping techniques facilitate weld inspection when abnormal weld characteristics are encountered.

The successful remote establishment of the four closure welds' integrity on two fueled SNAP-21 capsules provided final test certification.

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NONDESTRUCTIVE TESTING OF ISOTOPE
CONTAINMENT CAPSULES: SNAP-21 FINAL REPORT

R. W. Steffens

1.0 INTRODUCTION

Because of the toxic nature of the Strontium-90 isotope core material in SNAP-21 isotope capsules, it is imperative that container integrity be established so that the capsules can be safely used. Closure weld integrity is of particular concern due to the discontinuous container parameters at the weld joint. Ultrasonic weld inspection techniques and equipment which provide non-destructive test (NDT) quality assurance for the SNAP-21 closure welds were developed at Battelle-Northwest (BNW) under sponsorship of the Atomic Energy Commission* and, in cooperation with the Minnesota Mining and Manufacturing Company (3M Co.) and Oak Ridge National Laboratories (ORNL).

The ultrasonic SNAP-21 weld inspection test described in this report was the result of a BNW performed NDT program in support of the SNAP-21 closure weld development program at ORNL. The NDT program was separated into three phases. The first phase concerned the establishment of the initial design Tungsten Inert Gas (TIG) SNAP-21 and SNAP-23 closure weld characteristics.¹ The initial design SNAP-21 TIG weld characteristics were found to be less than optimum and the welding techniques were reevaluated by ORNL. The second phase concerned the establishment of the second design SNAP-21 TIG weld and initial design SNAP-21 electron beam (e. b.) closure weld characteristics. The initial design SNAP-21 e. b. closure weld characteristics were found to be more desirable than the second design TIG closure weld characteristics, and the e. b. closure weld technique was adopted as the closure welding technique for fueled SNAP-21 capsules.² The third phase concerned the development of the remote ultrasonic test station UT-40,³ and the optimization of the SNAP-21 ultrasonic e. b. weld inspection technique for remote implementation.

The UT-40 ultrasonic test station was delivered to and installed by ORNL in January 1968. Test station operation and SNAP-21 ultrasonic e. b. weld test

*United States Atomic Energy Commission Contract AT(45-1)-1830.

technologies were transferred to ORNL personnel during BNW personnel visits to ORNL in February and March 1968. The integrity of four closure welds on two Strontium-90 fueled SNAP-21 capsules was ultrasonically established during the March 1968 technology exchange. These inspections provided the final remote evaluation of the UT-40 test station and SNAP-21 weld inspection test. In addition to the SNAP-21 final test technology, optimum procedures for providing NDT support during isotope container development evolved.⁴ It should be noted that the successful ultrasonic inspection of the Strontium-90 fueled SNAP-21 capsules was the result of an extensive NDT support program which was made possible through the interlaboratory cooperation between the 3M Co., ORNL, and BNW during the container development phase.

This report provides a reference for implementing the SNAP-21 ultrasonic closure weld test through the detailed presentation of the test mechanics and parameters.

2.0 SUMMARY AND CONCLUSIONS

The SNAP-21 ultrasonic weld inspection test was developed to provide quality assurance of the peripheral e. b. closure welds on Strontium-90 fueled SNAP-21 isotope capsules. The ultrasonic test parameters were established during an extensive NDT program performed in support of the weld development program.^{1,2} The UT-40 ultrasonic test station facilitates implementation of the ultrasonic test for remote weld inspection.³

Three weld anomaly types--porosity, laminar voids, and unfused joint interfaces--were defined through metallographic verification of ultrasonic defect indications. These anomalies are optimumly oriented for detection with an ultrasonic beam aligned normal to the capsule wall. The weld volume is ultrasonically monitored with 0.003 in. pitch helical scans. Defect indications and beam position signals are synthesized into analog voltages in the UT-40 test console, and the combined data is read out on one of two types of X-Y weld parameter mapping techniques. The oblique X-Y mapping technique facilitates defect indication interpretation when small (maximum dimension of 0.050 in. or less), randomly oriented defects are detected. The pen lift X-Y mapping technique facilitates defect indication interpretation when large (0.050 in. axial length) unfused joint interfaces are detected.

Successful implementation of the SNAP-21 ultrasonic weld inspection test demands complete operator familiarity with the ultrasonic test parameters and the UT-40 test station. Special case ultrasonic signals can result from abnormal test surface conditions such as surface roughness or curvature. Unique defect indications can also be observed in the weld corner area. Implementation of test options are required to compensate for the above special cases. Wave shaping of the ultrasonic signal at the transducer with reactive tuning can be used to decrease the "noise" encountered with rough test surfaces. Oblique alignment of the transducer up to three degrees from normal in the axial direction is used to compensate for test surface curvature and to permit weld corner signal interpretation.

The SNAP-21 weld standard was fabricated to provide references for ultrasonic defect indication interpretation. Standard references are the flat bottoms of eight drill holes which range from 0.015 to 0.070 in. diameter. The flat bottoms are positioned parallel to the test surface and at the average weld anomaly depth below the test surface. Based on the test response to the smallest diameter (0.012 in.) standard reference and the close correlation obtained through metallographic and radiographic verification of defect indications on developmental weld samples, defects as small as 0.010 in. maximum dimensions can be ultrasonically detected in the SNAP-21 closure welds.

Final evaluation of the SNAP-21 ultrasonic weld test and UT-40 test station was performed with the remote inspection of four closure welds on two Strontium-90 fueled SNAP-21 capsules. Rough and curved test surfaces resulted from experiments performed during the three months between capsule fabrication and ultrasonic weld inspection. Thus, utilization of all test technology was necessary to establish the weld integrity. The integrity was established on all four welds, and each weld was qualified as per the weld acceptance criteria.⁵

The conclusions drawn from this ultrasonic weld inspection development program are both programmatic and technical. Programmatically, integration of ultrasonic NDT into the weld development program provides the three following functions. First, ultrasonic inspection of weld development samples supplements the data acquired through radiographic and dye penetrant analysis and enhances the metallographic weld analysis. Thus, undesirable weld characteristics are more reliably discovered during the weld development phase and welding techniques can be optimized. Secondly, the correlation between metallographic

and ultrasonic data is necessary to establish confidence in the ability to ultrasonically detect the undesirable weld parameters. The third programmatic function is the development of standard test references which simulate weld anomalies as close as possible, and thus, provide realistic calibration and interpretation of the ultrasonic defect indications. The above three programmatic functions facilitate the development of reliable test techniques.

The successful establishment of the weld integrities on two fueled capsules provides the most conclusive evidence that ultrasonic techniques can provide closure weld quality assurance. The NDT technology required to remotely inspect the SNAP-21 e. b. closure welds was the result of close cooperation between the ORNL weld development personnel and BNW, NDT methods development personnel.

3.0 DISCUSSION

3.1 Capsule and Weld Description

SNAP-21 capsule and weld characteristics pertinent to the ultrasonic test inspection are shown in Figure 3.1. The diameter and axial length of the right cylindrical clad are 3.2 in. and 3.34 in. respectively. This clad has three components--a cylindrical wall fabricated from Hastelloy-C bar stock and two lids fabricated from Hastelloy-C plate stock. One lid has a handle which facilitates remote capsule handling. The lids are joined to the cylindrical wall with e. b. welds, and establishment of the weld integrity is the ultrasonic test objective.

The lid rests on a 0.050 inch deep, 0.170 inch long counterbore in the cylindrical wall, and the lid edge-counterbore wall, weld joint interface is to be tested. This interface is sealed with a peripheral e. b. weld positioned parallel to the cylinder axis. The weld volume is classified into three axial sections to comply with the weld acceptance criteria.⁵ The first 0.020 in. from the outer corner is the weld corner area, the 0.150 in. from the weld corner to the counterbore face is the weld specification area, and the area below the counterbore face is the weld root area. Weld characteristics in the weld specification and weld corner areas are to be ultrasonically established.

The weld is inspected with an ultrasonic beam incident on the cylinder wall, and the first 0.5 in. from both ends is designated the "test surface".

The physical properties of the test surface are critical to the optimum implementation of the ultrasonic test. This area should have a 64 RMS finish, be flat, and the outer corner should be square.

3.2 Weld Characteristics

Three weld characteristics shown in Figure 3.2 were defined during the ultrasonic test development program performed on six Phase II SNAP-21 developmental welds. The most common anomalies are laminar cracks characteristic of those in the Figure 3.2-B photomicrograph. The laminar cracks are located approximately parallel to the test surface and may be connected to porosity type voids. Porosity type voids typical of those in the photomicrograph of Figure 3.2-D are the second most common anomalies observed in the weld. It should be noted at this point that the vast majority of the two anomalies described above are located in the weld root area where they do not undermine the integrity of the weld.

Failure to fuse a portion of the lid edge-counterbore wall interface due to a misaligned weld volume is shown in the Figure 3.2-C photomicrograph. The axial length of the unfused joint constitutes an undesirable weld specification area anomaly.

The ultrasonic test equipment, techniques, and procedures developed at BNW to detect and record these three anomalies are described in the following sections of this report.

3.3 UT-40 Test Station

The UT-40 test station³ shown in Figure 3.3 was developed and fabricated at BNW for remote implementation of the SNAP-21 ultrasonic weld inspection test. The test station was transferred to ORNL in January 1968, and test station operation training for ORNL personnel was accomplished at ORNL during February and March of 1968. It should be noted that thorough test operator familiarization with the UT-40 test station is required before attempting to ultrasonically establish a SNAP-21 weld's integrity with the test technique described in this report.

Briefly, the tester consists of two parts: (1) an ultrasonic test tank placed in the hot cell, and (2) an electronic console placed outside the cell. The test tank provides: (1) capsule rotation, (2) axial ultrasonic transducer translation, (3) linear and angular ultrasonic transducer positioning, (4) devices to monitor the location of the incident ultrasonic beam on the capsule, and (5) provisions for circulating cooling water. The electronic console provides:

(1) motor controls for the test tank, (2) electrical power for the ultrasonic-beam position monitoring devices, (3) broadband excitation for the ultrasonic transducer and amplification of the resulting signals, (4) analog synthesis of the ultrasonic signals, and (5) recording of defect signals as a function of circumferential and axial defect position on the capsule. An oscilloscope is used with the test station for equipment setup and test signal monitoring.

Specific test station parameters which influence the performance of the SNAP-21 ultrasonic weld test are described in the relevant test description sections.

3.4 General Test Description

SNAP-21 ultrasonic weld inspection test mechanics are shown in Figure 3.4. The weld anomalies described in section 3.2 are optimumly orientated for pulse-echo test mode detection with an ultrasonic beam aligned normal to the cylinder wall. The ultrasonic beam is generated with a lithium sulphate (LiSO_4) or PZT-5, 3/4 in. diameter, 15 MHz, spherically focused transducer. This beam is aligned normal to the cylinder wall and positioned at a distance from the wall such that the beam focal area is centered in the wall and at the original weld joint depth. Ultrasonic energy reflected from an anomaly is detected by the transducer and the resulting broadband signal is synthesized into an analog signal for the recorder. An adapter placed on the transducer directs a flow of water on the face of the transducer, along the beam water path, and onto the test surface. This flow thermally protects the transducer's active element, disperses thermal gradients in the water, and removes gas bubbles from the test surface. The weld volume is thoroughly scanned with the ultrasound by rotating the capsule at 3 rpm and translating transducer axially at 0.003 in. per revolution. This helical scanning is performed automatically with the UT-40 test station.

The counterbore face is the weld specification area and weld root area boundary. This cylinder wall discontinuancy is reliably detected by observing the point where the ultrasonic signal from the wall inner surface decreases to 50 percent of its full amplitude. Thereby, the counterbore face is used as an axial defect position reference. The weld specification area has an axial length of 0.150 inches. Based on the scanning rate of 3 rpm and 0.003 axial inch per revolution, approximately 17 minutes are required to inspect a weld.

Obliquely incident beam angles up to ± 3 degrees from normal in the axial direction can be advantageously used for inspecting the weld corner area or slightly curved test surfaces. Interpretation of ultrasonic data obtained at incident angles other than normal is considerably more complex than in the normal incidence case as described in section 4.4. All ultrasonic test results are standardized through use of the standard described in section 6.0.

3.5 Data Readout

Ultrasonic defect indications can be automatically recorded on the UT-40 X-Y recorder with one of two types of defect indication maps as shown in Figure 3.5. Oblique X-Y weld defect indication maps (Figure 3.5-A) provide convenient data interpretation when randomly oriented defects such as laminar cracks and porosity are being monitored. Each trace of the recording is one complete scan around the circumference of the capsule. Every second revolution is recorded to prevent data loss during pen retrace. The transducer is translated axially 0.003 in. per rev.; thus, a trace is recorded every 0.006 in. Analog defect indication signals are electrically added to the beam position voltages, and these indications appear as "spikes" on the map. The counterbore reference is observed on an oscilloscope trace of the ultrasonic signal, and the test operator marks the reference trace on the map.

Pen lift defect indication maps (Figure 3.5-B) provide convenient data interpretation when portions of unfused joints (Figure 3.2-C) are monitored. The recorder pen is set down only when a defect indication is detected and at the beginning and end of each trace (trace markers). Trace length is equivalent to one revolution, and traces are recorded every 0.006 inch.

Defect indication interpretation and specific recording parameters are given in sections 6.3 and 4.8 respectively.

FIGURE 3.1
SNAP-21 Capsule and Weld Description

A. Weld with Laminar Void and Unfused Joint (See B & C)

B. Laminar Type Void (Arrows)

C. Unfused Joint (Arrow)

D. Porosity Type Void (Arrow)

FIGURE 3.2
Anomalies in SNAP-21 e.b. Closure Welds

FIGURE 3.4
Ultrasonic Defect Detection Test for SNAP-21 e.b. Closure Welds

A. Oblique X-Y Weld Defect Indication Map

B. Pen Lift X-Y Weld Defect Indication Map

FIGURE 3.5
X-Y Recordings of SNAP-21 Ultrasonic Defect Indications

4.0 ULTRASONIC TEST PARAMETERS

4.1 Basic Ultrasonic Signals

The SNAP-21 ultrasonic weld inspection test is based upon the interpretation of three ultrasonic signals obtained by aligning an ultrasonic beam normal to the test surface. The signals are the surface reflection, the inner surface reflection, and defect reflections, and their characteristics and origins are shown in Figure 4.1. The surface reflection (R_s) is used to initially align the transducer and as a reference for gating the defect signals. The UT-40 main amplifier saturates at ± 3 volts, and the unsaturated, and saturated, R_s signals are shown in Figure 4.1 oscillograms A and B respectively. The R_s signal amplitude is maximum when the ultrasonic beam is aligned normal to the surface and the beam focal point is at the surface. Thus, observation of the unsaturated R_s signal amplitude is the basis for initial transducer alignment. The R_s signal amplitude is much greater than the defect reflections (R_D) and inner surface reflection (R_{is}), and R_s saturates the main amplifier at the amplification required to detect the R_D signals as shown in oscillogram B of Figure 4.1. The R_s signal duration determines the minimum depth below the surface that an R_D signal can be detected. R_s signal durations less than 0.75 microseconds are required to insure complete inspection of the weld volume. Under normal testing conditions with the UT-40 test station, the R_s signal duration is less than 0.5 microseconds. The saturated surface reflection is detected and used to trigger the gate pedestal delay. Thus, accurate gate position is maintained during scanning. The R_s amplitude drops below the gate delay trigger threshold as the beam transverses the weld corner and the gates no longer function. Maintenance of a stable R_s amplitude in the weld specification test area is essential.

SNAP-21 weld defects can be located from 0.070 in. to 0.200 in. below the outer cylinder surface, and a defect indication signal (R_D) can occur from 0.75 to 1.8 microseconds after the surface reflection. The rf representation of a typical defect indication is shown in oscillogram D of Figure 4.1. Through the use of the UT-40 noise-rejection detector circuitry, R_D signals with signal-to-noise ratios of 2:1 can be detected.

The reflection from the inner wall surface (R_{is} - Figure 4.1, oscillogram C) is used as a signal amplitude and defect position reference. The R_{is} amplitude is normally two to three volts when the beam focal point is positioned at the weld depth (oscillogram B, Figure 4.1).

Constant R_{is} signal amplitude between the standard's R_{is} and a weld test capsule's R_{is} indicates consistent ultrasonic test parameters. The counterbore face reference position is established by noting the point where the R_{is} signal decreases to 50% of full amplitude as the beam translates axially across the reference (oscillogram C, Figure 4.1).

False R_D signals from the weld surface can occur in the weld corner test area, and inspection of the weld corner test area is treated as a special case in section 4.3.

4.2 Special Case Ultrasonic Signals

Test surface geometries which vary from the specified capsule design were encountered during the test development phases and must be considered in this report. Specifically, curved, rough, and inadequate machine surface finishes can significantly reduce test performance if compensation procedures are not made.

Inadequate machine surface finishes can cause excessive surface signal duration expansion. Excessive surface signal ringing, Figure 4.2 oscillogram, increases defect signal area noise level and may completely mask defect signals. Surface signal ringing increases as the ultrasonic beam frequency increases. The problem can often be rectified by lowering the ultrasonic energy frequency. Lowering the ultrasonic beam frequency below 10 MHz can impair the test sensitivity to defects less than 0.015 inch in diameter. Thus, test surface remachining to the specified 64 RMS finish is recommended whenever possible.

Rough surfaces caused by thick oxide layers or mineral deposits can severely attenuate or scatter the ultrasonic beam at the surface and cause an excessive noise level in the defect signal time domain. Test interference due to surface deposits can be detected by monitoring the R_{is} and/or R_S signals for amplitude variations. Rough surfaces can normally be avoided by testing welds immediately after weld fabrication.

Curved test surfaces not parallel to the capsule axis require special attention. Curved surfaces are indicated by premature loss of the gate due to insufficient R_S amplitude. The three degrees oblique test option described in section 4.4 provides the basis for signal interpretation in tests where the ultrasonic beam is not normal to the test surface.

4.3 Weld Corner Area Signals

The weld corner area exhibits signals unique to that area, and additional signal interpretation techniques must be employed. The origins and signal time domains of five possible weld corner signals are shown in Figure 4.2. One or more of these signals can occur when the ultrasonic beam is centered within approximately 0.040 inch of the weld corner. Two signal types occur--those detected through a metal path (R_1 , R_2 , and R_3) and those detected through a water path (R_4 and R_5). The velocity of the ultrasound is approximately 0.059 inch per microsecond in water and 0.228 inch per microsecond in Hastelloy-C. Thus, a reflection from a weld surface protrusion located 0.020 to 0.070 inch from the weld corner will occur in the same signal time domain as a reflection from a weld defect 0.080 to 0.210 inch below the test surface.

Three techniques may be employed to differentiate between water path (false defect indications) and metal path signals. An ultrasound reflector placed above and parallel to the outer wall surface will direct the ultrasound away from the water path reflection surfaces and will remove the false indications. Another possible technique to differentiate between the two signal types is to observe the distance of the maximum defect indication amplitude from the counterbore reference point. Peak amplitude of a metal path defect indication should occur within 0.160 inch of the counterbore face. Peak amplitude of a water path false defect indication signal should occur more than 0.170 inch from the counterbore face.

The third possible technique to differentiate between the real and false defect indications is a three degree oblique test option described in the following section.

4.4 Oblique Incident Test Option

Alignment of the transducer beam up to three degrees away from normal in the capsule's axial plane is advantageous if welds with curved surfaces or weld corner defect indications are encountered. Axial position interpretation of defect indications observed with an obliquely incident test is complicated by the following parameters. The defect indication distance from the counterbore reference is dependent on defect depth below the test surface as shown in Figure 4.3. Unfused portions of the lid-counterbore face joint influence the ultrasonic reference point when the beam is obliquely incident. The reference

point will appear to be slightly closer to the weld surface when the beam is angled toward the capsule corner and will appear to be slightly further away from the weld surface when the beam is angled toward the capsule center.

The hypothetical case where two defects (D_1 and D_2) occur the same distance from the counterbore, but at different depths, is shown in Figure 4.3. The deepest defect is detected before the defect which is closer to the surface. When the ultrasonic beam incident angle and defect depth are known, actual defect position can be calculated by use of trigonometry and Snell's Law.

Weld corner area inspection is enhanced when the beam is angled obliquely toward the capsule end due to the beam refraction at the water-Hastelloy-C interface. As can be noted in Figure 4.3, the obliquely incident ultrasonic beam is centered back from the weld corner when the ultrasonic beam is scanning the corner portion of the weld. Thus, more of the beam is incident on the capsule than in the normal incidence case, and more energy is available for detecting weld corner area defects. Additionally, the weld corner will mask many weld surface protrusions from the ultrasonic beam, and the probability of "false" defect indications is reduced.

The three degree oblique test sensitivity does not appear to be significantly reduced as compared to the normal incident test sensitivity. Standard calibration charts for both tests are given in section 6.

4.5 Transducer Alignment Parameters

The SNAP-21 weld inspection test transducer is spherically focused and proper focal point positioning in the recast metal volume is necessary to achieve adequate test sensitivity. Use of the undistorted rf surface reflection to obtain normal incidence beam alignment on the test surface and at the beam focal point is described in section 4.1. The water path time (time between transducer excitation and surface signal return) is approximately 72 microseconds at normal incidence alignment with the focal area on the surface. Due to focusing, the ultrasonic energy converges toward the beam center. Figure 4.4 shows resulting beam refraction when the test surface is inside the focal point. The refraction of beam reduces the focal area length and diameter as compared to the beam's focal characteristics in the water. Maximum test sensitivity is obtained when the focal area is positioned in the recast weld metal. The effect of translating the transducer toward the test surface, and thereby, placing the focal area inside the metal, is shown in

Figure 4.4. The surface signal amplitude decreases as the transducer moves toward the test surface, while the defect and inner surface signal amplitudes increase. The focal point is centered at the depth of the original weld joint when the water path time is approximately 62 microseconds. Actual alignment is accomplished by aligning the beam normal to standard's test surface and directly over the 0.020 in. diameter standard reference. The reference signal amplitude will increase as the transducer is translated toward the test surface. The beam's focal point is properly positioned in the recast weld metal area at the point where the maximum amplitude of the reflection from the 0.020 reference hole is observed.

4.6 Heat Considerations

Ultrasonic water velocity changes due to thermal gradients in the test tank water can cause erratic ultrasonic signal amplitude and water path time fluctuations. Refraction of the ultrasonic beam as it passes through thermal water gradients disperses the beam and can severely undermine test reliability. In addition to the ultrasonic beam considerations, water temperatures over 90°F can destroy a LiSo_4 transducer element.

The adapter diagrammed in Figure 3.4 was designed to overcome the above problems. Water pumped into the inlet is directed onto the transducer face through 20 holes in the inner adapter surface. The water is reflected off the transducer face, out the front of the adapter, along the ultrasonic beam water path, and off the test surface. The UT-40 test tank water volume sufficiently absorbs the fueled SNAP-21 thermal energy and an external coolant water supply is not necessary. Precooling of fueled capsules before placement in the UT-40 test tank is recommended to prevent unnecessary addition of heat.

4.7 Electronic Signal Synthesis Parameters

UT-40 electronic console amplification, gating, and detection functions each have optional settings which must be adjusted by the test operator. Detailed test console operation is given in Reference 3, and thus, only the parameter significance and utilization will be discussed herein.

Amplification of 40 db to 55 db is available in the main UT-40 amplifier. Minimum gain (40 db) is usually sufficient for SNAP-21 weld test signal amplification. Noise levels of 60 millivolts or less at the amplifier output is optimum for signal gating and detecting; however, higher noise levels can

be tolerated due to the noise rejection circuitry incorporated into the detector circuitry. If less than 40 db gain is required, during transducer alignment for instance, the input signal can be attenuated with the UT-40 attenuator pad.

A surface follower gate operation mode is used in the SNAP-21 weld test. The gate is referenced to the surface reflection with a variable delay. The leading edge of the gate pedestal is set with the gate delay and the lagging gate pedestal edge is set with the gate width potentiometer. The gate pedestal leading edge should be set approximately 1.0 microsecond from the surface reflection leading edge. The gate pedestal lagging edge should be set as close to the inner surface reflection as possible. Caution should be exercised during the gate positioning to insure rejection of outer and inner surface reflection "noise".

Negative portions of the gated signals are detected by charging a capacitor through a single diode detector. The capacitor is biased with an adjustable negative voltage which permits noise rejection. The capacitor is reset to the "noise rejection" voltage shortly before each gated signal is detected. The detector output stage inverts the detected waveform and the analog voltage is positive when observed on a CRT. Noise rejection is optimally set when the detector output remains constant during the gate time interval under "no defect signal" conditions. The noise rejection level is set most effectively while aligned on the standard and verified on the test capsule below the weld root area.

4.8 Recording Parameters

SNAP-21 weld defect maps are X-Y representations of the circumferential position voltage, axial position voltage and analog defect signal voltage. These voltages are operated upon by pen lift, summing amplifiers, and diode limiting techniques to obtain the desired defect map.

Two capsule revolutions are required to drive the circumferential position potentiometer through one 0 to +15 volt revolution. Thus, every second capsule revolution occurs during a linear portion of the position voltage. The axial position voltage ranges from 0 to +15 volts for one inch axial transducer travel. The transducer travels 0.003 inch per capsule revolution and thus, the axial position voltage varies 0.045 volt per capsule revolution. Analog defect signals can range from 0 to +6 volts.

Pen lift, summing amplifier, and diode limiting circuits prepare analog position and defect signal voltages for input to the X-Y recorder. The SNAP-21 test calibration is based upon the number of revolutions a particular defect is recorded. Diodes can be used at the detector output to limit the defect analog voltages to any value below six volts. Amplitude limited analog defect voltages enhance the oblique X-Y defect indication map interpretation. UT-40 pen lift circuitry automatically releases the recorder pen to be set down during alternate capsule revolutions. The pen is set down as a function of detector output and pen lift reference voltages. When the pen lift reference voltages are set to zero, the pen will remain down during the entire duration of every second revolution (see oblique X-Y defect map in Figure 3.5). When the pen lift reference voltages are set above zero, the pen will set down only when the detector output voltage exceeds the reference voltage amplitude. (See pen lift X-Y defect map in Figure 3.5.)

Test information recorded when the pen is set down is a combination of the position and defect voltages. These voltages are combined with the summing amplifiers in the UT-40 test console. The quiescent summing amplifier output voltage can be varied from -15 to +15 volts to facilitate recorder setup. Three analog voltages can be combined in each summing amplifier for inputs to drive the X-Y recorder pen or carriage. In addition, provisions are available in the UT-40 tester to individually attenuate the analog voltages, if desired.

Oscillograms are 0.5 Microseconds per cm.

FIGURE 4.1
Relationships Between the Basic SNAP-21 Weld Test Signals
and the Weld Cross Section

FIGURE 4.2
Special Case Signal Origins and Time Domain

FIGURE 4.3
Signal Position Interpretation for 3° Oblique Test

FIGURE 4.4
Ultrasonic Beam Focal Area Position Parameters

5.0 VERIFICATION OF ULTRASONIC DEFECT INDICATIONS

Extensive metallographic and radiographic analyses of ultrasonic defect indications were used to provide supplementary data for establishment of test parameters and weld characteristics. The weld characteristics presented in section 3.2 of this report and in previous SNAP-21 reports were the results of metallographic and radiographic analysis of ultrasonic defect indications. Correlation among ultrasonic and metallographic-radiographic data establishes confidence in the ability to ultrasonically detect the pertinent weld characteristics.

Weld anomalies of major concern in the ultrasonic defect indication verification problem are small cracks and/or porosity with maximum dimensions of 0.020 in. or less. This type defect is not easy to locate metallographically in the SNAP-21 welds. The metallographic analyst should be provided with maximum NDT support to aid the metallographic analysis, and thus, obtain maximum information from a particular weld sample. The following section describes techniques used during the SNAP-21 ultrasonic test development program to verify ultrasonic defect indications and to establish test parameters and weld characteristics.

5.1 Ultrasonic Defect Indication Verification Techniques

The test sequence and sample preparation techniques presented in the following paragraphs were developed during the SNAP-21 ultrasonic weld test development program. Weld development and NDT personnel can derive optimum benefit from a weld sample when this procedure is implemented. The indication verification sequence and pertinent operations are shown in Figure 5.1.

Initially, the weld volume is ultrasonically scanned and the defect indication locations and ultrasonic defect signal characteristics are recorded. Several ultrasonic scanning techniques are usually employed during the test development period to enhance the probability of detecting as many weld anomalies as possible. The exact nature of the ultrasonically indicated weld anomalies is determined through radiographic and metallographic analysis of the indication area.

The weld sample lids and inner liner are removed to enhance the radiographic inspection of the weld volumes as shown in diagram II of Figure 5.1. When the lids are removed without destroying any part of the recast metal weld volume, the weld sample retains its value for further ultrasonic scanning

in the event the radiographic results indicate further weld inspection is needed. At least one wall thickness in the radial direction should be conserved in the weld areas after lid removal. Thus, after lid and inner liner removal, the weld sample will be a hollow cylinder with a constant wall thickness.

The entire weld area is radiographed after lid and inner liner removal as shown in diagram III of Figure 5.1. Exposures are made every 30° around the circumference. The radiographic, and ultrasonic, data are compared; and if defects were radiographically indicated, but not ultrasonically indicated, further ultrasonic test development is performed. When radiographic and ultrasonic data correlate, defect indications to be metallographically analyzed are selected and the ultrasonic data which characterizes the defect indications are recorded. The metallographic sample is then removed from the weld as shown in the Figure 5.1-V diagram. Axial cuts should be made at least 0.050 inch to each side of the weld anomalies to insure anolay conservation. Recommended metallographic sample axial length is 0.400 inch or longer. The metallographic sample is then radiographed in three directions as shown in the Figure 5.1-V diagram. Two significant advantages in radiographically inspecting the metallographic sample are: (1) the anomaly position in the metallographic sample is determined, which facilitates the metallographic analysis, and (2) the metallographic sample geometry is optimum for radiographic detection of weld anomalies which were not previously indicated.

The ultrasonic and radiographic data is tabulated and presented to the metallography analyst to enhance his analysis of the sample. The sample is ground and polished on an axial face and in incremental steps. Photomicrographs are taken of the weld cross section when significant weld anomalies are found.

Intercorrelation among ultrasonic, radiographic, and metallographic data defines the possible weld defect types and establishes the confidence with which a defect can be ultrasonically detected. The following section presents a typical set of data obtained with this development and verification sequence.

5.2 Defect Indication Verification Example

The Hastelloy-C stock from which the SNAP-21 cylinder walls were fabricated was changed from seam welded tubing to bar stock after ultrasonic test

development was performed on the initial e. b. weld samples. Extensive ultrasonic defect indication verification analyses were performed on the initial e. b. weld samples and confidence in the ability to ultrasonically detect the undesirable weld characteristics was established.² The close correlation among the ultrasonic and metallographic data presented in the following paragraphs verifies that the material stock change was not detrimental to the SNAP-21 test sensitivity. Thus, the verification results obtained on the initial e. b. welds are valid and apply to the establishment of confidence in the ability to ultrasonically inspect final design SNAP-21 e. b. welds.

Pertinent results from an ultrasonic defect indication verification sequence on a capsule with material and weld characteristics typical of the final SNAP-21 material and design specifications are shown in the photomicrographs and oscillograms of Figure 5.2. The Figure 5.2-A photomicrograph shows a 0.017 inch axial length porosity in the weld specification zone. This defect presence was indicated by the ultrasonic defect indication in the Figure 5.2-A oscillogram. Porosity location is established with respect to the counterbore face reference and the inner surface as shown in the Figure 5.3 diagram. Ultrasonic and metallographic location data is tabulated in the Figure 5.3 table. Close correlation among the D_1 location data establishes the D_1 defect indication validity. Validity of the ultrasonic indications of an unfused joint and a defect in this weld sample was similarly established with close correlation among ultrasonic and metallographic defect location data. The photomicrograph of the unfused joint (D_2) and weld root defect (D_3) and an oscillogram of the respective ultrasonic defect indications are shown in Figure 5.2-B. Location data are compared in the Figure 5.3 table, and as can be noted, close correlation exists. The signal-to-noise ratios of the ultrasonic defect indications were well above the 2:1 ratio required for signal synthesis by the UT-40 test console.

FIGURE 5.1
Weld Sample Inspection and Ultrasonic Defect Indication Verification Sequence

TABLE 5.1
COMPARISON OF ULTRASONIC AND METALLOGRAPHIC
DEFECT INDICATION VERIFICATION DATA

Defect Parameter		D ₁	D ₂	D ₃
A				
Distance from Counterbore face	met.	0.024 in.	0.002 in.	0.082 in.
	u/s	0.025 in.	0.004 in.	0.088 in.
B				
Distance from Inner Surface	met.	0.119 in.	0.045 in.	0.080 in.
	u/s	0.115 in.	0.046 in.	0.080 in.
C				
Axial Length	met.	0.017 in.	0.0095 in.	0.035 in.
u/s Sig. amp	u/s	0.9	0.7	1.7

Metallographic Data Origins

Ultrasonic Data Origins

FIGURE 5.3
Correlation Among Metallographic and Ultrasonic Defect
Indication Verification Results

D₁ Ultrasonic Defect Indication
2 Microseconds per cm.

A. Weld Specification Area Defect Indication and Correlating Metallographic Results

D₂ Ultrasonic Defect Indication
2 Microseconds per cm.

D₃ Ultrasonic Defect Indication
2 Microseconds per cm

B. Unfused Joint and Weld Root Defect Indications and Correlating Metallographic Results.

FIGURE 5.2
Defect Indication Verification Results on Final Design
SNAP-21 e.b. Weld Sample

6.0 TEST STANDARDIZATION AND CALIBRATION

6.1 Standard Description

The SNAP-21 test standard in Figure 6.1 was designed to facilitate test setup and ultrasonic defect indication interpretation. Test standard design is based upon ultrasonic test sensitivity data obtained during the test development phases, consideration of possible weld defects, and weld acceptance criteria. Weld anomalies described in section 3.2 and shown in Figure 3.2 are oriented with their maximum dimension approximately parallel to the capsule axis. Flat bottomed holes drilled 0.080 in. deep radially from the inner surface simulates the SNAP-21 e. b. weld anomalies. The standard was fabricated to the actual SNAP-21 capsule dimensions and from Hastelloy-C bar stock representative of the fueled capsule clad material.

Nine holes with diameters from 0.010 to 0.070 inch were fabricated into the SNAP-21 ultrasonic test standard. Three holes, one 0.10 in. dia. and two 0.015 in. dia., were fabricated with an edm (electrodischarge machining) technique, and the other five were fabricated with a drilling technique. Eight holes were spaced every 45° around the standard circumference, 0.080 in. deep, and centered 0.100 in. from the corner. Thus the hole bottoms are placed in the weld specifications area and at the average recast weld metal depth. Effective hole bottom diameters range from 0.012 in. (the minimum verified detectable defect diameter) to 0.070 in. (the specified maximum allowable defect diameter). These eight reference hole bottoms provide ultrasonic defect indication interpretation in terms of the weld acceptance criteria and ultrasonic test parameters. The ninth hole, a 0.015 in. dia. edm hole, was fabricated within 0.005 in. of the corner by ORNL. This hole bottom provides a standard reference to evaluate the 3° oblique test effectiveness in the weld corner area.

Flat bottom, small diameter edm holes such as the 0.010 and 0.015 in. dia. SNAP-21 standard holes are difficult to fabricate. The effective flat bottom diameters of the 0.015 in. dia. edm holes are between 0.012 and 0.013 in. which satisfies the standardization of the minimum verified detectable defects. The effective diameter of the 0.010 in. dia. edm hole is less than 0.005 inch, and therefore, it does not factor into test standardization or calibration.

6.2 Standard Calibration Recordings

The interpretation of SNAP-21 closure weld defect indications is based upon X-Y recordings of the test response to the standard defects. Standard calibration recordings should be performed both before and after a weld test to establish the test integrity.

Typical normal incident and 3° oblique test standard calibration recordings are shown in Figure 6.2. The standard calibration recording obtained prior to a weld test is most significant. This recording must display detection sensitivity and recording stability typical of the Figure 6.2 recordings before a weld quality assurance test is performed. Test response to the 0.015 inch diameter simulated defect is the major guideline. This standard defect must be detected on at least three traces and each indication must have greater amplitude than the "noise" observed on any trace.

The standard calibration recording in Figure 6.2-B shows the 3° oblique test response to the 0.015 inch diameter weld corner area edm hole. Note that the test sensitivity to the standard defects is not seriously impaired under oblique test conditions.

6.3 Defect Indication Interpretation

The number of traces a defect indication is recorded on the X-Y recording forms the basis for defect axial length correlation between defect and standard calibration indications. Note that the distance between each trace represents 0.006 inch of ultrasonic beam axial travel, and therefore, the number of traces the defect indication is recorded is representative of the defect axial length. The readout of the axial length of a defect facilitates the interpretation of the defect indications in terms of the weld acceptance criteria.

Observation of the calibration recording in Figure 6.2-A shows that the product of the indication traces and 0.006 inch is always larger than the actual defect axial length, and caution must be exercised to prevent overestimation of the defect axial length. The defect's axial length is interpreted by correlating the number of traces the defect is observed with tracings on the calibration recording.

FIGURE 6.1
SNAP-21 Ultrasonic Test Standard Description

FIGURE 6.2
Normal Incident and 3° Oblique Standard Calibration Recordings

7.0 REMOTE TEST IMPLEMENTATION ON TWO FUELED CAPSULES

Final evaluation of the SNAP-21 ultrasonic weld inspection test and the UT-40 ultrasonic test station was performed by establishing the integrity of the four welds on two fueled SNAP-21 capsules. In addition to the weld inspections, this series of tests provided the final transfer of SNAP-21 test technology from BNW to ORNL personnel.

7.1 Interlaboratory Technology Exchange

The ultrasonic test data which establishes the closure weld integrity on fueled capsules Nos. 2 and 3 are presented in the two following sections (sec. 7.2) and 7.3). Two technology exchanges between BNW and ORNL nondestructive testing personnel were held before the fueled capsule welds were inspected. The first technology exchange occurred at ORNL six weeks before the fueled capsule inspection. At this time, the UT-40 test station was checked for operability after being shipped from BNW to ORNL. The UT-40 test station operation and SNAP-21 weld inspection test implementation were explained and demonstrated to ORNL personnel. Test tank modifications to facilitate remote manipulation were discussed, and the necessary modifications were made by ORNL before the final technology exchange.

The two fueled capsules displayed ideal characteristics for evaluating all aspects of the SNAP-21 ultrasonic weld inspection test. The final technology exchange occurred during the fueled capsule weld inspection sequence. Initially, the remote operation of the UT-40 test station was checked by performing ultrasonic weld inspections on "nonradioactive" weld sample capsules immediately prior to the inspection of the fueled capsules.

Exploratory weld inspections were performed on the fueled capsules after the UT-40 remote performance was established. Inner surface reflections from the fueled capsules were typical of those observed on the standard capsule, and this established the validity of interpreting the weld defect indications with use of standard calibration charts. No adverse thermal effects were observed which verified the waternozzle effectiveness.

The two fueled SNAP-21 capsules (Nos. 2 and 3) were assembled three months prior to the ultrasonic inspection of the weld. The capsules had undergone hydrostatic pressure testing which resulted in a slight radius over the test surfaces. Nonstandard surface finishes were encountered on the test surfaces of fueled capsule No. 3, and high noise levels in the defect signal time domain

were encountered. Implementation of ultrasonic wave shaping techniques effectively reduced the noise level to acceptable values. The radiused weld test surfaces on two welds prevented weld integrity establishment with the normal incident test; however, implementation of the 3° oblique test option was successful.

7.2 Weld Integrity Establishment on Fueled Capsule No. 2

The X-Y recordings of the ultrasonic calibration and weld inspection series in which the handle end weld integrity was established and the background data for inspecting the bottom end weld were obtained are presented in Figure 7.1. The oblique X-Y recording technique with diode limiting was used throughout the fueled capsule weld inspections. The Figure 7.1-A standard calibration recording was obtained immediately before the weld inspections shown in Figure 7.1-B and 7.1-C. The standard calibration recording in Figure 7.1-B was obtained immediately after the weld inspection test. Note that test sensitivity and recording stabilities were the same at both the beginning and end of this test series.

The ultrasonic test data displayed in the Figure 7.1-B defect indication recording establishes the capsule No. 2 handle end closure weld integrity. As can be noted, no defect indications as large as the calibration responses to the 0.015 in. standard reference were observed, and the test was valid over 28 traces. The 28 traces are equivalent to 0.168 inch axial travel from the counterbore face reference toward the weld corner. By allowing 0.010 inch axial length for the minor type defect indications which were observed, the minimum nondefective axial weld metal length is 0.158 in. The 0.158 in. of high integrity weld metal more than adequately meets the weld acceptance criteria.

Figure 7.1-C displays the bottom end ultrasonic test data. Note a high incidence of defect indications in the counterbore face reference area and the presence of unfused portions of the joint. The first trace was positioned 37 traces (0.222 in.) toward the capsule center from the counterbore face reference. Note that no defect indications were observed in the weld root test area other than those associated with the highly concentrated defect area around the reference.

The two crosses on the Figure 7.1-C recording mark the first "no indication" tracings in line with the longest portions of unfused joint indications.

The longest portion of the unfused joint was indicated on eight (8) consecutive traces. Eight traces are observable on the standard recording from the .0405 in. standard reference. Thus, a maximum unfused joint axial length of 0.040 inch was indicated.

This normal incidence test was valid over only 18 traces (0.108 in.). The test ended prematurely due to loss of sufficient surface reflection amplitude for initiating gating system. The cause of surface signal amplitude was due to a slight curvature of the test surface. As can be noted, no defect indications were observed in the weld specification test area other than those near the reference.

The difference between the valid test axial length (0.108 in.) and the maximum indicated defect axial length (0.040 in.) is the verified "no defect" axial length (0.068 in.). Based on this test, the 0.040 in. maximum defect length is not cause for rejection, and the 0.068 "no defect" length is insufficient to accept the weld. The two weld root area defects indicated on the Figure 7.1-C recording provide convenient references for establishing the circumferential orientation of the ultrasonic test data recordings in Figure 7.2.

The 3° oblique test option was implemented on the capsule No. 2 bottom end closure weld to compensate for the radiused test surface. The standard calibration recording in Figure 7.2-A was obtained immediately before test series presented in Figure 7.2. The Figure 7.2 standard calibration recording was obtained with the ultrasonic beam aligned 3° from normal toward the capsule center in the axial direction. Note that standard defect indication sensitivity on the 3° oblique test (Figure 7.2-A and 7.3-D) is typical of the sensitivity observed with the normal incidence test (Figure 7.1-A and 7.1-D).

The ultrasonic defect indication recording obtained during the inspection of the capsule No. 2 bottom end closure weld with the 3° oblique test option is shown in Figure 7.2-B. The cross marks the first "no-defect-indication" trace observed after the maximum axial length unfused-joint indication. Comparison of the weld root area reference defect indications in Figures 7.1-C and 7.2-B show that the maximum axial length unfused-joint indication occurred at the same circumferential position on both the normal incidence and 3° oblique test recordings. Eighteen traces (0.108 in.), on which no significant defect indications occurred, were recorded after the last maximum axial length unfused joint indication. The 0.108 in. is the minimum "no defect" weld metal path.

Thus, the integrity of the bottom end closure weld on the fueled capsule was established, and this weld is within the SNAP-21 weld acceptance criteria.

The ultrasonic defect indication recording in Figure 7.2-C was obtained on the capsule No. 2 bottom end closure weld immediately after the integrity of this weld was established as described above. The 7.2-C defect indication recording was obtained with the ultrasonic beam aligned 3° from normal toward the capsule corner in the axial direction (as compared to 3° oblique toward the capsule center in Figure 7.2-B and normally incident as in Figure 7.1-C). Although the Figure 7.2-C recording had no significance in the establishment of the bottom end closure weld integrity, it does provide an educational function. Note that only four valid test traces (0.024 in.) were observed after the maximum axial length unfused joint indication. This compares with twelve traces (0.072 in.) in the normal incident test and eighteen traces (0.108 in.) in the 3° oblique toward the capsule center test. The above test degradation, as the ultrasonic beam is rotated axially from 3° oblique toward the capsule center to 3° oblique toward the capsule corner, demonstrates the necessity of using care in ultrasonic transducer alignment and in 3° oblique test implementation.

7.3 Weld Integrity Establishment on Fueled Capsule No. 3

The X-Y recordings of the ultrasonic calibration and weld inspection series in which the integrity of both closure welds on the fueled capsule No. 3 were established is presented in Figure 7.3. The oblique X-Y recording techniques with diode limiting was used in this inspection series. An excessive noise level in the defect signal time domain was encountered during the exploratory evaluation of this capsule. A transducer with a LiSO_4 active element was used because of its compatibility with wave shaping techniques. The standard calibration recording in Figure 7.3-A was obtained immediately before the weld inspection with the ultrasonic beam aligned normal to the test surface. Note the stability of traces in the "no indication" areas as compared to the standard calibration obtained with a PZT-5 transducer in Figures 7.1-A, 7.1-D, and 7.2-A. However, some amplitude sensitivity was sacrificed on the 0.015 standard defect indications in the wave shaping process.

The normal incidence ultrasonic test data displayed in the Figure 7.3-B defect indication recording establishes the capsule No. 3 bottom end weld integrity. The defect indication characteristics of this weld are quite similar to the characteristics of the bottom-end weld on fueled capsule No. 2. Note

the high incidence of defect indications at the counterbore reference. The cross indicated by the arrow marks the last indication of the maximum axial length defect indication. This defect indication originates at the step and is observed on twelve traces in the weld specification test area. The .0405 in. reference standard has eleven trace indications and the 0.0525 in. reference has fifteen trace indications. Thus, a defect of approximately .0043 in. axial length is indicated. The twenty-seven valid traces recorded in the weld specification test are equivalent to 0.162 in. axial length. The last seventeen traces display no defect indications. The difference between defect length and the valid test length is 0.119 in. and this is the minimum "no defect" axial weld metal length. The 0.119 in. is within the weld acceptance criteria, and thus the integrity of the bottom-end weld was established.

The normal incidence ultrasonic test data displayed in the Figure 7.3-C defect indication recording indicates the presence of a 0.043 in. axial length unfused joint in the handle end closure weld. Only fourteen valid traces (0.084 in axial length) were recorded; thus, the weld could neither be accepted or rejected on the basis of this test.

The 3° oblique test option was implemented with the beam directed toward the capsule center. The 3° oblique ultrasonic test data in Figure 7.3-E establishes the capsule No. 3 handle-end closure weld integrity. Twenty-six valid traces (0.156 in axial length) were recorded with this 3° oblique test. Since no defect indications were recorded in the last sixteen traces, the 0.043 in. long unfused joint is the most significant defect indication. The difference between valid test axial length (0.156 in.) and unfused joint length (0.043 in.) is the minimum "no defect" weld metal axial length -0.113 inches. The 0.113 in. is within the weld acceptance criteria and thus the integrity of the bottom-end weld was established.

A. Pre-Test Standard Calibration Recording

B. Handle End Weld Defect Indication Recording

C. Bottom End Weld Defect Indication

D. Post Test Standard Calibration Recording

FIGURE 7.1
Ultrasonic Calibration and Inspection Charts on Fueled
SNAP-21 Capsule No. 2-Handle End Weld Integrity Established

A. Pre-Test Standard Calibration Recording

B. Bottom End Weld Defect Indication Recording

C. Bottom End Weld Defect Indication Recording

FIGURE 7.2
Ultrasonic Calibration and Inspection Charts on Fueled
SNAP-21 Capsule No. 2-Bottom End Weld Integrity Established

A. Post Test Standard Calibration Recording - Normal Incident

B. Bottom End Defect Indication Recording Normal Incident

C. Handle End Weld Defect Indication Recording Normal Incident

D. Post Test Standard Calibration Recording

E. Handle End Weld Defect Indication Recording

FIGURE 7.3
Weld Integrity Establishment on Fueled Capsule No. 3

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