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**NONDESTRUCTIVE TESTING
OR ISOTOPE CONTAINMENT CAPSULES
PHASE I SNAP-21 AND SNAP-23**

R. W. STEFFENS
H. N. PEDERSEN
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JANUARY, 1968

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NONDESTRUCTIVE TESTING OF ISOTOPE CONTAINMENT CAPSULES
PHASE I SNAP-21 AND SNAP-23

By

R. W. Steffens, H. N. Pedersen, and F. M. Coffman

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NONDESTRUCTIVE TESTING OF ISOTOPE CONTAINMENT CAPSULES
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ABSTRACT

Because of the toxic and radioactive nature of the core material contained in isotope heat sources, it is imperative that the integrity of the container be assured through a reliable quality control program. This program must include measurements capable of providing both quality assurance of the product and information feedback for process control. In the case of isotope containment capsules, standard radiographic techniques are not capable of detecting the small volume cracks typically found in the closure welds. To solve the quality control problem, an ultrasonic test system has been devised to provide accurate and reliable measurements of the container closure weld parameters. Specifically, tests have been devised (1) to measure the depth of weld penetration, (2) to detect cracks in the weld volume, and (3) to detect excessive meltdown of the outer weld corner.

This report (1) describes the ultrasonic techniques developed for the evaluation of weld quality on the three-pass, peripheral end-cap weld on SNAP-21 and SNAP-23 isotope containment capsules, (2) discusses the verification of the ultrasonic measurements using the results of extensive metallographic analysis, and (3) includes an evaluation of the three-pass weld technique.

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NONDESTRUCTIVE TESTING OF ISOTOPE CONTAINMENT CAPSULES
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INTRODUCTION

Because of the toxic nature of the core material contained in an isotope source, it is imperative that the container integrity be established so that the source can be safely used. Establishment of the integrity of the closure weld is of particular concern due to the discontinuous container configuration at the weld joint. Two techniques that have been used to attempt to establish weld integrity are metallographic and radiographic analysis of the weld. These two techniques are not readily adapted to the problem of quality assurance of isotope sources because (1) radiography is difficult to perform in the presence of high radiation fields and (2) metallographic analysis provides only statistical information on the actual weld. Ultrasonic nondestructive testing techniques have overcome both of these shortcomings and have been shown capable of providing fast continuous monitoring of those capsules having right circular cylinder geometries. In addition to providing assurance of closure weld integrity, nondestructive ultrasonic techniques have been shown to be a valuable tool for weld design evaluation.

The application of nondestructive testing (NDT) techniques for establishing isotope containment capsule integrity began in 1963 at Pacific Northwest Laboratories (PNL) to supplement the promethium program sponsored by the Division of Isotope Development (DID)*. At the request of the Minnesota Mining and Manufacturing Company (3M Company), this program was expanded to include a feasibility study to determine the applicability of ultrasonic NDT for the establishment of weld integrity on SNAP-21 containment capsules. The results of this study were promising and were followed by a request for the development of ultrasonic NDT that could be adapted to remote

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

operation for the establishment of weld integrity on the preliminary design SNAP-23 isotope containment capsules. Since the weld configuration of the SNAP-23 capsules is essentially the same as that of the SNAP-21 capsules, the feasibility study also provided a firm base for the development of ultrasonic NDT for the SNAP-23 capsules.

This report contains (1) a description of the ultrasonic techniques developed, (2) test evaluation procedures and the associated metallographic data, and (3) information concerning adverse weld characteristics.

The weld closures which are discussed in this report were made at the Oak Ridge National Laboratories (ORNL). They performed this work with neither time nor funding to develop a weld technique or mechanical jiggling. Thus, the information contained in this report should not be construed as containing any indication whatsoever of ORNL's weld design or weld performance capabilities.

This report is intended as an illustration of the type of quality control and process design information which can be obtained by proper application of available technologies.

DISCUSSION

CAPSULE AND WELD DESCRIPTION

Seven inert (nonradioactive) weld samples simulating the dimensional and material characteristics of Phase I, SNAP-21 and SNAP-23 isotope containment capsules were supplied by the 3M Company for use in the development of ultrasonic techniques to evaluate the peripheral end-cap closure weld. Figure 1 shows the pertinent physical characteristics of the inert weld samples. These characteristics are indicated by number and are referred to in the following paragraphs by the respective number in parentheses. The weld samples were fabricated from seam welded Hastelloy tubing with a Hastelloy disk welded on one end. The cylindrical containers and the end caps were fabricated by the 3M Company, and the peripheral closure welds, which seal the joint between end cap and the counterbore wall in the cylinder, were performed at ORNL. The peripheral closure welds were of the Tungsten Inert Gas (TIG) type and were fabricated using a three-pass technique -- one pass on each side

of the joint and the final pass directly over the joint. The diameter of the cylinder at the weld end was reduced 0.020 in. to allow for a 0.010 in. radial cylinder expansion due to meltover by the outermost weld pass. A minimum of 0.100 in. weld penetration is specified with no weld root cracking or cylinder expansion exceeding the unreduced nominal cylinder diameter.

WELD EVALUATION

Before proceeding with the description of the ultrasonic techniques employed, a discussion of the weld characteristics is in order to permit better understanding of the test philosophy and procedures. The material presented in this section was acquired during an extensive metallographic analysis performed to evaluate the ultrasonic tests.

The weld cross section shown in Figure 1B has sufficient weld penetration, no weld root cracking, and had excessive cylinder expansion machined off without damage to the weld. A weld cross section with insufficient weld integrity is shown in Figure 1C. In addition to the weld root crack, this weld has less than the specified 0.100 in. penetration over a large portion of the weld surface. Note that the distance from the weld-wall corner, Point 7, to the counterbore corner, Point 8, is shorter than the unwelded joint length, Point 3, in the defective weld in Figure 1C and longer than the joint length in the acceptable weld in Figure 1B. When the weld-wall corner length, Point 11 is shorter than the unwelded joint length, the probability of obtaining the specified 0.100 in. weld penetration is greatly reduced as shown in Figure 2. Note further that the lack of penetration extends over a considerable portion of the outer weld bead and is caused by excessive meltdown of the outer capsule corner by the outer weld pass. This adverse weld characteristic was more predominant in the SNAP-23 samples than in the SNAP-21 samples. The reason may be seen by noting that the counterbore depth is two-thirds of the wall thickness in the SNAP-23 samples as compared to one-half the wall thickness in the SNAP-21 samples.

The probability of weld root cracking is increased when the weld penetration of the inside or outside passes at the joint is greater than the penetration of the final, directly-above-the-joint pass. Figure 3 shows a series of weld root cracks found on SNAP-21 Sample 4. Note that the weld root cracks occur in either the weld volume of the inner or outer weld passes, and the direction of propagation from the joint is dependent on the angle at which the weld volume crosses the joint. (The outer weld pass seemed to predominate and therefore, the crack tended to propagate toward the cylinder wall as shown in Figure 3B.) This effect was particularly adverse on SNAP-23 samples because the outside of the weld was also the area of least penetration.

COMPATIBILITY OF WELD CONFIGURATION WITH ULTRASONIC NDT

Reproducible ultrasonic test results require a smooth, dimensionally consistent outer surface geometry where the ultrasonic wave enters the test sample. This prevents beam scattering and facilitates transducer alignment. Since the surface geometry of the present weld design varies considerably in each sample and between samples, it is difficult to detect small areas such as weld root cracks or to directly measure weld penetration through the weld surface.

The unwelded joint length (4) and the weld height (3) are readily measured with ultrasonic beams normally incident on the cylinder wall and the weld bead respectively. The difference in length between these two measurements is weld penetration. Thereby, a practical method of measuring weld penetration exists. Weld root cracks propagating toward the outer cylinder wall are ideally oriented for detection with an ultrasonic beam aligned obliquely to the cylinder wall.

ULTRASONIC TEST DEVELOPMENT

The initial step to prepare for the ultrasonic test development phase was to metallographically analyze weld Sample 4 to obtain the weld's cross sectional characteristics and to define possible problem areas. To prepare the remaining six weld samples for test development, the cylinder walls were machined smooth to remove the 0.010 in. step and weld meltover from the critical testing areas over the counterbore step and the end of the joint at the weld root. This machining

step also removed the irregular area on the cylinder wall at the seam, thus allowing ultrasonic transducer alignment to be maintained as the capsule was rotated. Index marks (2), Figure 1, were scribed every 5° around the cylinder to both facilitate recording of the experimental ultrasonic data and to reference this data to the subsequent metallographic analysis. The laboratory equipment used during the development of the ultrasonic tests is shown in Figure 4. The versatile ultrasonic test tank provided three-dimensional transducer alignment, two-dimensional capsule rotation, and calibrated horizontal transducer translation. The broadband ultrasonic tester provided excitation for the ultrasonic transducer and amplification of the detected ultrasonic signals. The oscilloscope provided visual data readout, and the associated camera provided permanent recording of pertinent waveforms. Although transducer translation and sample rotation was manually performed during test development, these functions may also be automatically performed with this test tank.

Ultrasonic measurements pertaining to weld height, unwelded joint length, and detection of weld root cracks were recorded every 2° around each weld sample by using several different ultrasonic test techniques. Reproducibility of the ultrasonic measurements was then checked by repeating the measurements of the unwelded joint length obtained with two different test techniques.

When the recording of the ultrasonic data was completed, areas on the welds displaying typical data were sectioned every 2° to obtain metallographic samples. These samples were polished, etched, and photographed with calibrated magnification, and the actual weld height, unwelded joint length, weld root crack severity, and weld-wall corner length were then determined from these photomicrographs. The metallographic data were then compared with the ultrasonic measurements for test evaluation. The results are given in the following section.

ULTRASONIC TEST DESCRIPTIONS AND EVALUATIONS

A three-ultrasonic-transducer technique was developed for the nondestructive certification of weld integrity on the preliminary design SNAP-21 and SNAP-23 isotope containment capsules. The transducer

locations selected for inspecting the welds are shown in Figure 5, where Transducers 2 and 3 are used to measure weld penetration and Transducer 1 is used to detect weld root cracks. Transducer 2, aligned normal to the cylinder wall, is used to measure the unwelded joint length and to establish the position of the weld wall corner with respect to the position of the weld root. Transducer 3, aligned normal to the weld bead, is used to measure weld height. The difference between the unwelded joint length and the weld bead, is used to measure weld height. The difference between the unwelded joint length and the weld height is weld penetration. Transducer 1 is aligned at 19.6° with respect to a line normal to the cylinder wall and in a plane containing the longitudinal cylinder axis; thereby, a shear wave is generated which propagates in the wall at 45° with respect to the surface and toward the weld end. This ultrasonic beam is used to detect weld root cracks, and it may also be used as a "back-up" test for the normal incidence test for measurement of the unwelded joint length.

NORMAL INCIDENCE MEASUREMENT OF JOINT LENGTH

Test Description

Measurement of the unwelded joint length and the establishment of the position of the weld-wall corner with respect to the end of the joint at the weld root is performed with ultrasonic Transducer 2 (Figure 5). The transducer is initially aligned normally incident on the surface of the cylinder wall over an area adjacent to the core volume of the sample as shown in Position 1 of Figure 6. The oscillogram at Position 1 shows the full amplitude of the unobstructed surface reflection and this amplitude is used as a reference for detection of the weld-wall corner at Position 5. The full amplitude of the unobstructed reflection from the unwelded portion of the joint, shown in the oscillogram at Position 3, is recorded and used as a reference for the detection of the counterbore corner and the end of the joint at the weld root.

The unwelded joint length is measured by translating the ultrasonic transducer from Position 1 to Position 5 and recording the resultant translation distances between Positions 2 and 4. The ultrasonic signal

at Position 2 is characterized by the growth of the reflection from the unwelded joint at the counterbore corner to 50% of the full amplitude of the unobstructed reflection at Position 3, as may be seen by comparing the signal at Position 2 to the signal at Position 3. The ultrasonic signal at Position 4 is characterized by the reduction of the reflection from the end of the joint at the weld root to 50% of the full amplitude of the unobstructed reflection at Position 3, as may be seen by comparing the signal at Position 4 to the signal at Position 3.

Establishment of the location of the weld-wall corner with respect to the end of the unweld joint length is obtained by measuring the transducer translation distance between Positions 4 and 5. Position 5 is characterized by reduction of the surface reflection at the weld-wall corner to 50% of the amplitude from the unobstructed surface reflection at Position 1 as shown in the respective oscillograms at Positions 1 and 5. For data interpretation purposes, the transducer locations at Positions 4 and 5 are referenced to Position 2 and the translation distance is obtained by observing the difference between the unwelded joint length and the weld-wall corner length (Points 3 and 11, Figure 1).

Test Evaluation

The ultrasonic normal incidence measurements of unwelded joint length and the weld-wall corner length obtained on SNAP-23 samples were evaluated by graphic comparison with measurements taken metallographically. Weld areas displaying typical ultrasonic data were sectioned every 2° and metallographically analyzed to obtain the required comparison data.

The two characteristic types of ultrasonic data obtained with the normal incidence technique during measurement of unwelded joint length and weld-wall corner length were observed in an 80° section of SNAP-23 Capsule 6. These data are graphically shown in Figure 7. In the 25° section from 140° to 165° the ultrasonic measurement of unwelded joint length is 0.050 to 0.070 in. shorter than the weld-wall corner length; however, this difference suddenly decreases to 0.020 in. at 170° and remains at 0.020 in. through to 220°. Since there is little variation between the two curves in the 170° to 220° section, it is indicated that

the measurement of the unwelded joint length is being influenced by the relationship of the weld-wall corner location with respect to the end of the unwelded joint.

The correlation between the metallographic and ultrasonic measurements of unwelded joint length and weld-wall corner lengths obtained over a 70° section on Capsule 7, which is an area typical of the 140° to 165° section of Capsule 6, is shown graphically in Figure 8. As is noted in Figure 8, the ultrasonic measurements of the weld-wall corner length correlated within plus or minus 0.010 in. with the respective metallographic measurements, as did the measurements of the unwelded joint length when a 0.010 in. bias is added to the ultrasonic measurements. This section of the weld was characterized by the weld-wall corner length being at least 0.030 in. longer than the unwelded joint length. Therefore, it may be concluded that ultrasonic measurements of the unwelded joint length with the 0.010 in. bias added are valid when the difference between the ultrasonically measured weld-wall corner length and the unwelded joint length exceeds 0.030 mils.

The results of the metallographic measurements of unwelded joint length and weld-wall corner length on an 80° section of Capsule 9, which displayed ultrasonic data typical of the 170° to 220° section of Capsule 6, is shown graphically in Figure 11. As may be noted in Figure 11, this section of the weld is characterized by the weld-wall corner length being shorter than the unwelded joint length. This is an adverse characteristic of the weld since the probability of attaining the specified 0.100 in. weld penetration is greatly reduced (Figure 2). It is thereby concluded that when the difference between ultrasonically measured weld-wall corner length and the unwelded joint length approaches 0.020 in., the weld exhibits areas of excessive meltdown of the outer weld corner. It is further noted, however, that when excessive outer weld corner meltdown exists, the normally incident ultrasonic measurement of unwelded joint length is invalid and the ultrasonic 45° shear wave technique must be used if the actual unwelded joint length is desired.

45° SHEAR WAVE MEASUREMENT OF JOINT LENGTH AND DETECTION OF WELD ROOT CRACKS

Test Description

In addition to the capabilities for automatic remote-controlled detection of weld root cracks, ultrasonic Transducer 1, Figure 1, may be used to measure the unwelded joint length by a manual technique. Use of the 45° shear wave ultrasonic technique for the measurement of the unwelded joint length is necessary in areas of the weld where excessive meltdown of the outer weld corner is detected by the normal incidence technique. To perform this test, the transducer is aligned obliquely to the cylinder wall surface at 19.6° and in a plane containing the longitudinal cylinder axis. Due to ultrasonic beam refraction at the surface, the shear wave generated in the container wall propagates toward the weld at 45° with respect to the wall surface as shown in Figure 9. The unwelded joint length is determined by measuring transducer translation between the detection of the outer corner of the counterbore step at Position 1 and the detection of the weld root at Position 2, Figure 9. The weld root crack is detected at Position 3 as shown.

The manual technique for measuring the unwelded joint length relies upon the reflection of the ultrasonic energy at the counterbore corner for a reference signal. At Position 1, Figure 9, the location of the detected reflection from the counterbore corner is noted on the oscilloscope graticule and the transducer location is recorded from the calibrated transducer translation mechanism. An oscillogram which displays a typical counterbore step reflection is shown at Position 1. As the transducer is translated from Position 1 to Position 3, a maximum amplitude reflection is detected at the weld root crack. Since the weld root crack generally propagates toward the wall surface, the ultrasonic beam travels less distance in the cylinder wall than the signal detected at Position 1. This can be seen by comparing the signal at Position 3 with the signal at Position 1. To locate the end of the

unwelded joint at the weld root the ultrasonic transducer is translated from Position 3 toward Position 1 while the test operator observes the amplitude and time movement of the signal reflected from the weld root crack. Detection of the weld root is characterized by the point at which the reflection from the weld root crack appears at the same position on the oscilloscope graticule as the reflection from the counterbore step. This can be seen by comparing the signal at Position 2 with the signal at Position 1.

The net transducer translation between Position 1 and Position 2, Figure 9, is equal to the unwelded joint length. If there is insignificant weld root cracking, the signals received at transducer Positions 2 and 3 occur at the same position on the oscilloscope graticule, and the maximum reflection amplitude is only slightly above the electronic noise level. Therefore, an operator skilled in ultrasonic reflection interpretation is required to perform the unwelded joint length measurement. When significant weld root cracking exists the reflection at Position 3 is well above the electronic noise level of the associated equipment and may be readily detected. Evaluation of the above procedure for measurement of the unwelded joint length with the 45° ultrasonic shear wave technique is given in the following section.

Test Evaluation

The experimental ultrasonic measurements of unwelded joint lengths obtained with the 45° shear wave technique were initially evaluated by comparison with measurements obtained at the respective data points with the normal incidence technique. The final evaluation was performed by comparing the data with measurements obtained metallographically.

The typical data evaluation graph shown in Figure 10 compares the unwelded joint length obtained with the 45° shear wave technique on the 0° to 80° section of the weld on SNAP-23 Sample 9 with the measurements obtained at the respective data points using the normal incidence

technique. Also included on this graph is the distance of transducer translation between the counterbore corner and the maximum signal reflection from the weld root crack. This 80° section of Sample 9 displayed characteristics similar to the weld section on Sample 7 as shown in Figure 8 where the normal incidence measurement of the unwelded joint length was shown to be valid when a 0.010 in. bias was added to the measurement. Note that the measurement of unwelded joint length with the 45° shear wave technique correlates well with the normal incidence measurements and is an average of 0.010 in. longer than the normal incidence measurements. This approach provided confirmation of the validity of the 45° shear wave test before the expensive metallographic analysis was performed. This 0 to 80° section of Sample 9 had large amplitude ultrasonic reflections from weld root cracks. Gross weld root cracking was also indicated by the large transducer translation distance (up to 0.030 in.) between the weld root and maximum crack reflections as shown in Figure 10. The photomicrograph in Figure 10 shows a large weld root crack found in the weld area adjacent to the 0° data point.

The unwelded joint lengths measured with the 45° shear wave technique on the weld section of SNAP-23 Sample 9, from 225 to 305° were compared graphically with the measurements obtained metallographically on samples sectioned at the respective data points. This 80° section of Sample 9 covered an area where excessive outer corner meltdown existed. That is, the weld corner to counterbore face length was shorter than the unwelded joint length. Validity of the unwelded joint lengths measured with the 45° shear wave technique may be seen in Figure 11, where the ultrasonic measurements of unwelded joint length correlated within ± 0.010 in. with the metallographic measurements. This section of the weld displayed low amplitude reflections from the weld root cracks, and the photomicrograph in Figure 11 shows the small weld root cracks found in this area.

MEASUREMENT OF WELD HEIGHT

Test Description

Weld height is measured by using the ultrasonic beam from Transducer 3 (Figure 5), which is aligned normally incident on the weld bead and slightly to the inside of the unwelded joint. Reflections of the ultrasonic signals from the weld surface and from the bottom of the end cap are shown in the oscillogram in Figure 12. The time between the surface echo and bottom echo reflections is proportional to the distance between the weld surface and end cap bottom. Thus, it is a measure of weld height.

Test Evaluation

The experimental ultrasonic measurements of weld height obtained on SNAP-21 Sample 11 with the above technique were evaluated by comparing them with data obtained metallographically. The correlation between the ultrasonic and metallographic measurements is shown in Figure 13. Correlation is also shown between the 45° shear wave measurement of the unwelded joint length and the respective metallographic measurements. The ultrasonic measurements correlated within ± 0.010 in. with the metallographic measurements.

The end caps on the test development capsules were not seated snugly on the counterbore face and spaces up to 0.025 in. between the end-cap bottom and counterbore face resulted. Since the unwelded joint length is measured with the counterbore corner as a reference point, and since the weld height is measured with the end-cap bottom as the reference point, an error in the calculation of weld penetration equal to the space between the step and end cap results. If there is no assurance that the end cap will be well seated on subsequent capsules, an electromechanical technique may have to be used to measure the weld height.

CONCLUSIONS

Through metallographic evaluation of the ultrasonic tests described in this report, it has been shown that these tests are informative and may be advantageously used to evaluate the weld integrity of the peripheral end cap welds on the preliminary design SNAP-21 and SNAP-23 isotope containment capsules. These ultrasonic techniques were used to (1) measure weld penetration within ± 0.010 in., (2) detect excessive outer weld corner meltdown, and (3) detect weld root cracks greater than 0.005 in. long propagating toward the cylinder wall.

It is further concluded that each new situation must be carefully considered and laboratory studies conducted as a basis for the custom development of tests for each new weld design.

FIGURE 1. Capsule and Weld Characteristics of SNAP-21 and SNAP-23 Weld Samples

FIGURE 2. Lack of Penetration on SNAP-23 Weld Sample

FIGURE 3. Weld Root Cracks in SNAP-21 Weld Sample

FIGURE 4. Electrical and Mechanical Equipment for Ultrasonic NDT

Reflected Ultrasonic Energy

Transducer 1 - Weld Root Crack Detection
Transducer 2 - Unwelded Joint Length
Measurement.

Transducer 3
Weld Height
Measurement

18

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FIGURE 5. Ultrasonic Transducer Locations for Establishment of Weld Integrity on SNAP-21 and SNAP-23 Weld Samples

FIGURE 6. Normal Incidence Ultrasonic Technique for Measurement of Unwelded

FIGURE 7. Typical Data Evaluation Graph of the Ultrasonic Normal Incidence Measurement of Unwelded Joint Length and Weld Wall Corner Length on SNAP-23 Weld Sample No. 6

FIGURE 8. Correlation Results Between the Normal Incidence Ultrasonic and the Metallographic Measurements of the Unwelded Joint Length on SNAP-23 Weld Sample No. 7

FIGURE 9. 45° Shear Ultrasonic Technique for Measurement of Unwelded Joint Length and Detection of Weld Root Cracks

FIGURE 10. Typical Data Evaluation Graph of the Ultrasonic 45° Shear Technique for the Measurement of the Unwelded Joint Length on SNAP-23 Weld Sample No. 9

FIGURE 11. Correlation Results Between the 45° Shear Ultrasonic and Metallographic Measurement of the Unwelded Joint Length on SNAP-23 Weld Sample No. 9

FIGURE 12. Normal Incidence Ultrasonic Technique for the Measurement of Weld Height

FIGURE 13. Correlation Results Between Ultrasonic and Metallographic Measurement of Weld Height and Unwelded Joint Length on SNAP-21 Capsule No. 11

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