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DEVELOPMENT OF NONDESTRUCTIVE TESTS FOR THE EXPERIMENTAL GAS-COOLED REACTOR FUEL ELEMENT

R. W. McClung
R. A. Nance

OAK RIDGE NATIONAL LABORATORY
operated by
UNION CARBIDE CORPORATION
for the
U.S. ATOMIC ENERGY COMMISSION

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METALLURGY DIVISION

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ABSTRACT

The Title I design fuel assembly and each of its components for the Experimental Gas-Cooled Reactor (EGCR) are described. The development of the specific nondestructive testing techniques for the evaluation of the components and the fabricated fuel capsule is presented. These techniques include penetrants, pulse-echo and resonance ultrasonics, radiography, eddy-currents, helium leak testing, and others. Discussion is made on the capabilities and limitations of these techniques for the specific inspection problems and reasons presented for the selection of the inspection requirements.

INTRODUCTION

The Nondestructive Test Development (NDT) Group has been developing the nondestructive inspection techniques which will be recommended for use on the EGCR fuel element and its component parts. Figure 1 is an exploded view of the EGCR Title I design fuel assembly. It consists of seven rod-type fuel capsules symmetrically arranged in a graphite support sleeve by means of top and bottom spiders. Basically, each of the fuel capsules consists of a stack of UO_2 pellets encapsulated in a 0.710-in.-o.d. x 0.020-in.-wall type 304 stainless steel tube. Other component parts for the fuel capsule proper are a midplane spacer to maintain proper separation between the respective capsules and the graphite sleeve, end caps for the welded closure of the capsule, and MgO pellets which separate the UO_2 pellets from the end caps. Figure 2 permits a better view of the individual parts. The recent pilot plant program for the assembly of fifty Title I fuel elements[1]

[1] E. A. Wick and R. L. Heestand, Manufacture of Fifty Prototype Fuel Elements for the EGCR, ORNL-2936 (Dec. 12, 1960).

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ORNL Photo 34951

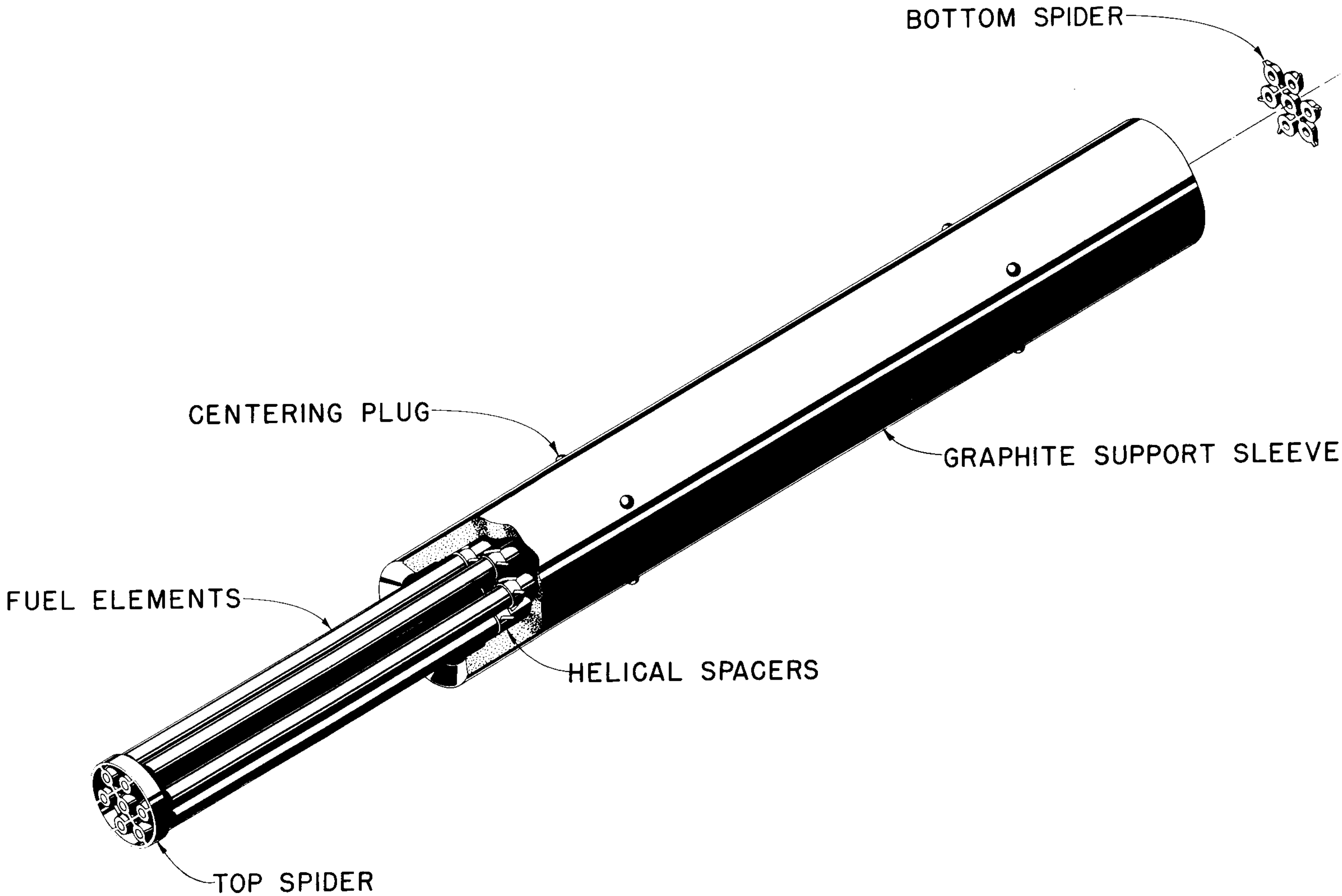

Fig. 1 Title I Design Fuel Assembly for EGCR.

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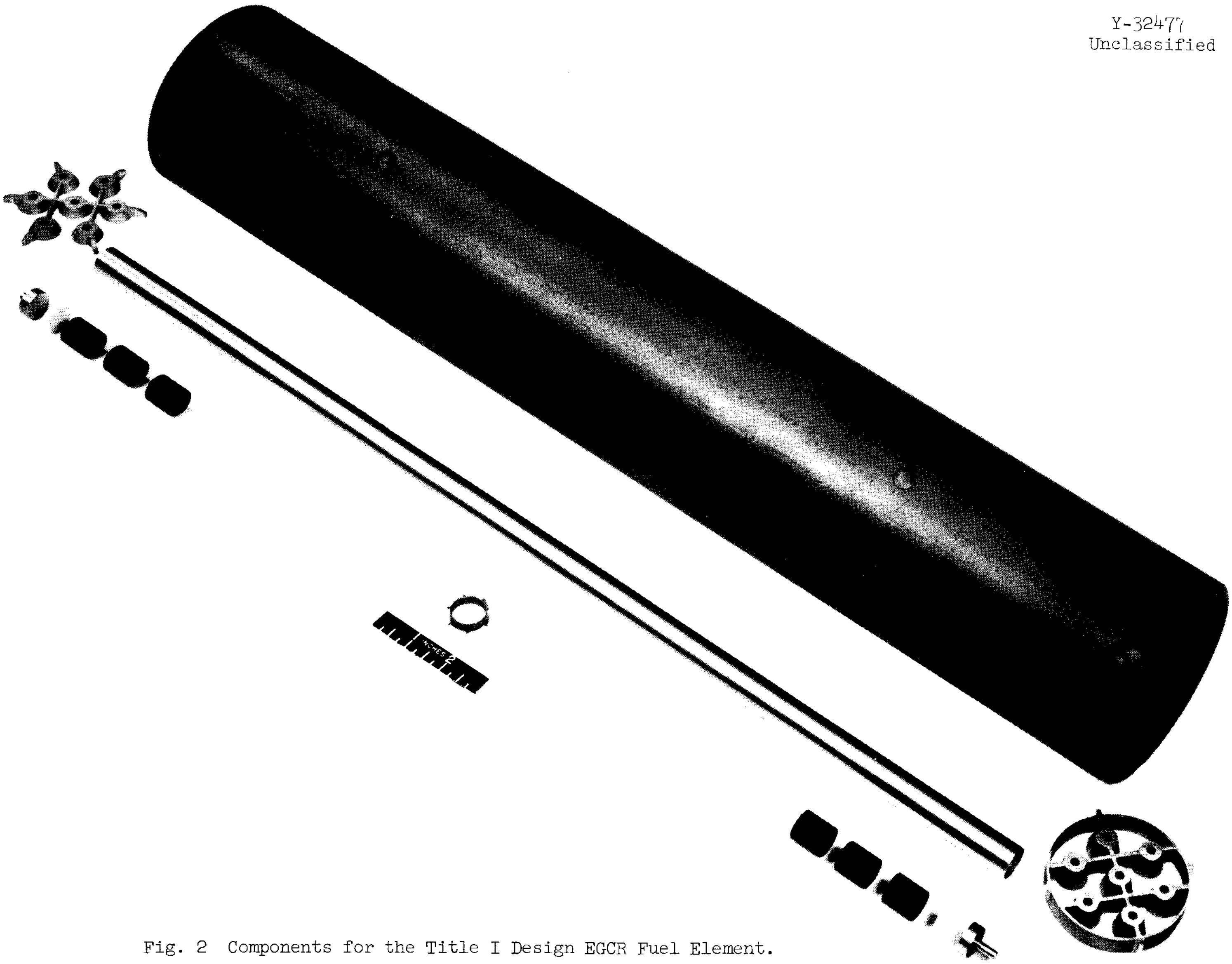

Fig. 2 Components for the Title I Design EGCR Fuel Element.

was used as a development step for the inspection techniques. Most of the component parts were procured in accordance with inspection requirements which had been established or developed at the time of component procurement. After receipt at the Oak Ridge National Laboratory (ORNL), the parts were completely reinspected. This served two purposes: (1) to establish a confidence level for the vendor inspection and (2) to determine the validity of the specific inspection details and make any necessary modifications. In addition, some new inspection techniques were developed which had not been utilized in the component procurement. Included in the inspection program were the fuel-capsule tubing, top and bottom end caps, midplane spacers, top and bottom spiders, the end closure welds, and the graphite sleeves. All of the material evaluation was conducted in the NDT Development Group Laboratory with the exception of the penetrant inspection on the tubing and the inspection of approximately one-half of the closure welds, both of which were conducted by the Inspection Engineering Department. Each of the inspection techniques which were used is discussed in this report.

TUBING

The most comprehensive nondestructive evaluation was conducted on the 0.710-in. i.d. x 0.020-in.-wall type 304 stainless steel tubing which is to be used as the fuel capsule cladding material. The techniques used for flaw detection were fluorescent penetrant, eddy-current, and pulse-echo ultrasonics. Air-gage and resonance-ultrasonic techniques were used for dimensional measurements.

Penetrant

The penetrant technique[2] should detect any defects which are open to the outer surface. The materials which were chosen for the inspection were ZL-22 penetrant, ZE-3 emulsifier, and ZP-4 developer.[3] The technique included

[2] R. B. Oliver, G. M. Tolson, and A. Taboada, "The Use of Penetrants for Inspection of Small Diameter Tubing," Symposium on Nondestructive Tests in the Field of Nuclear Energy, ASTM STP 223, Philadelphia, Pa., 1950.

[3] Manufactured by the Magnaflux Corporation, Chicago, Illinois.

precleaning, a penetrant soak for 30 min, an emulsification time of 1-1/2 min, a wash in a lukewarm-water spray, drying, 15 min development, and examination under a 100-w black-light source.

This technique was used on 600 of the 27.5-in. lengths. Any discontinuity was evaluated by physical removal to determine the depth. Those exceeding 0.0025 in. were considered cause for rejection of the tube. Eleven of the 600 pieces contained such defects and were rejected. These were primarily pit-like discontinuities.

Eddy Currents

The encircling-coil eddy-current technique[4] was used on the tubing in accordance with Spec. No. RMIS-7.(ref 5) The only deviation from the specification was the reference standard which was used. Instead of the specified transverse-filed notch, a longitudinal-milled notch was used. A study is in progress to determine the best notch-production technique, and the results will be used in a revision of Spec. No. RMIS-7.

An unsuccessful attempt was made by the tubing manufacturer to inspect the finished tubing using the above specification. This failure was due to the multiplicity of indications which were larger than those from rejectable discontinuities but were not caused by a defective condition in the tube. It is felt that many of these indications are due to small dimensional variations produced during the straightening operation. The presence of this "noise" (signals not associated with true defects) prevented a realistic eddy-current examination on the tubing and the eddy-current inspection requirement was waived for the manufacturer. However, it was demonstrated on 172 of the 600 pieces that a valid and realistic eddy-current test could be performed immediately after the final drawing operation and prior to the final anneal and straightening operation. The specification will be revised where necessary to permit the eddy-current inspection at this stage of the manufacture.

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[4] J. W. Allen, Eddy-Current Testing in Practice, ORNL-2655 (Apr. 16, 1959).

[5] "Procedure Specification for the Eddy-Current Inspection of Thin-Wall Austenitic Stainless Steel Tubing," Spec. No. RMIS-7, Appendix A of this report.

The results of the eddy-current examination performed at ORNL on the tubing were essentially the same as those determined at the vendor's plant. Only 13 of the 600 pieces could have been considered acceptable by strict conformance with the specification.

Pulse-Echo Ultrasonics

The pulse-echo ultrasonic technique[6] provided more detailed knowledge of the tubing quality. This inspection was not required of the vendor, nor is it anticipated that it will be a necessary part of future purchase specifications for this capsule tubing. It was used at ORNL to assist in establishing confidence levels in the other inspections and to assure the quality level of the tubing. This was particularly desirable since the eddy-current test was not useable on this "noisy" tubing. Although modifications of existing techniques permitted an increase in inspection speed by a factor of 4, it was still slower and more expensive than an eddy-current examination. The defect rejection level was the same as for the penetrant tests, i.e., any discontinuity with a depth exceeding 0.0025 in. The largest indications which were noted were from a few inner-surface mandrel marks having depths of from 0.001 to 0.002 in.

Air Gage

The air-gage measurements determined the conformance of the tubing to the inside-diameter tolerance of $0.710^{+0.002}_{-0.000}$ in. Twenty-two of the 600 lengths were found to exceed the specified dimensions and were rejected. All of these were out-of-round on the tube ends, probably due to deformation during or after final cutting to length.

Resonance Ultrasonics

The resonance ultrasonic technique[7] was used to measure the wall-thickness variation in the tubing and to assure its acceptability in accordance with the specified dimensions of 0.020 ± 0.002 in. Most of the tubing

[6] R. B. Oliver, R. W. McClung, and J. K. White, Immersed Ultrasonic Inspection of Pipe and Tubing, ORNL-2254 (Feb. 15, 1957).

[7] Robert C. McMaster (ed.), Nondestructive Testing Handbook, pp. 50.1–50.42, Vol. II, Section 50, The Ronald Press Company, New York, 1959.

exhibited wall thicknesses near the high side of the tolerance. Twenty-eight of the pieces were rejectable because of wall-thickness excursions which exceeded the tolerance. Only a portion of this tubing was examined at the vendor's plant by this technique. The results from their sampling indicated that approx 7% of the tubing failed to meet the wall-thickness tolerance as compared with the actual rejection at ORNL of less than 5%.

END CAPS

The top and bottom end caps, shown in Fig. 3, are machined from bar stock. The only nondestructive test proposed for these parts is the post-emulsification fluorescent-penetrant technique.[8] This should detect any defects which are open to the surface. The inspection materials chosen were the ZL-22 penetrant, ZE-3 emulsifier, and ZP-4 developer. The technique included precleaning by vapor degreasing, a penetrant soak for 30 min, an emulsification time of 3 min, wash in a lukewarm-water spray, drying, 15 min development, and examination under a 100-w black-light source. The emulsification time is one of the most critical portions of the technique. Shorter times were tried but machining marks on the concave section retained penetrant and presented strong indications under black-light examination. Evaluation demonstrated that these machining marks were less than 0.001 in. deep and were insignificant. Emulsification times longer than that specified would tend to remove the penetrant from significant defects. Four hundred seventy-five top end caps and five hundred seventy-four bottom end caps were examined by penetrants. All indications detected by this technique were evaluated by physical removal of the discontinuity. All of the discontinuities were removed within the dimensional tolerances and no rejection was made.

MIDPLANE SPACERS

The Title I design midplane spacer is shown in Fig. 4. The only nondestructive test proposed for the spacers is the post-emulsification

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[8] _Ibid._, pp. 6.1–6.24, Vol. I, Section 6.

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Fig. 3 Top and Bottom Caps for the Fuel Capsule.

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Y-35320

Fig. 4 Title I Design Midplane Spacer for the Fuel Capsule.

fluorescent-penetrant technique. The technique which was established for the end caps proved to be optimum for the five hundred ninety-eight spacers. Machining marks around the fins precluded shorter emulsification times. Burrs which had not been removed from the fins after machining caused the greatest number of indications but were not considered to be sufficient reason for rejection. All other indications were evaluated by physical removal of the discontinuity and were removed within the dimensional tolerance with no rejection being made.

SPIDERS

The inspection methods of fluorescent penetrant and radiography were used for the nondestructive evaluation of the investment-cast top and bottom spiders (illustrated in Fig. 5). An attempt was made to use the post-emulsification fluorescent-penetrant technique which was utilized for the inspection of the end caps and spacers. However, the difficulty in removing this type of penetrant from the as-cast surface of these parts caused a residual background of fluorescence which prevented any valid examination. For this reason a slightly less sensitive, water-washable fluorescent penetrant was used which could be removed from the casting surface. The materials used were ZL-1A penetrant and ZP-4 developer.[9] The technique included precleaning by vapor degreasing, a penetrant soak for 30 min, a wash in a lukewarm-water spray for 30 sec, drying, 15 min development, and examination under a 100-w black-light source. The wash time is one of the most critical portions of the technique. Shorter wash time may leave a residual fluorescent background on the specimen surface which would make examination difficult. Longer wash times may tend to remove the water-washable penetrant from defects.

Fifty-six of the bottom spiders and ninety-five of the top spiders were examined using the penetrant technique with only linear or crack-like indications being considered significant for this inspection. If the discontinuity could be removed within the dimensional tolerance, the spider was considered to be acceptable. Several discontinuities were detected

[9] Manufactured by the Magnaflux Corporation, Chicago, Illinois.

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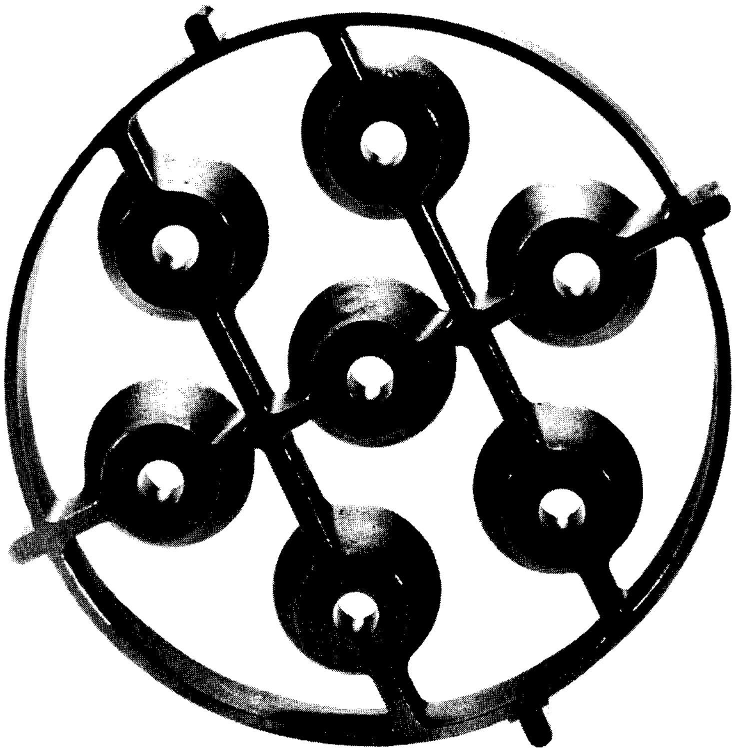
ORNL Photo 48811



Top

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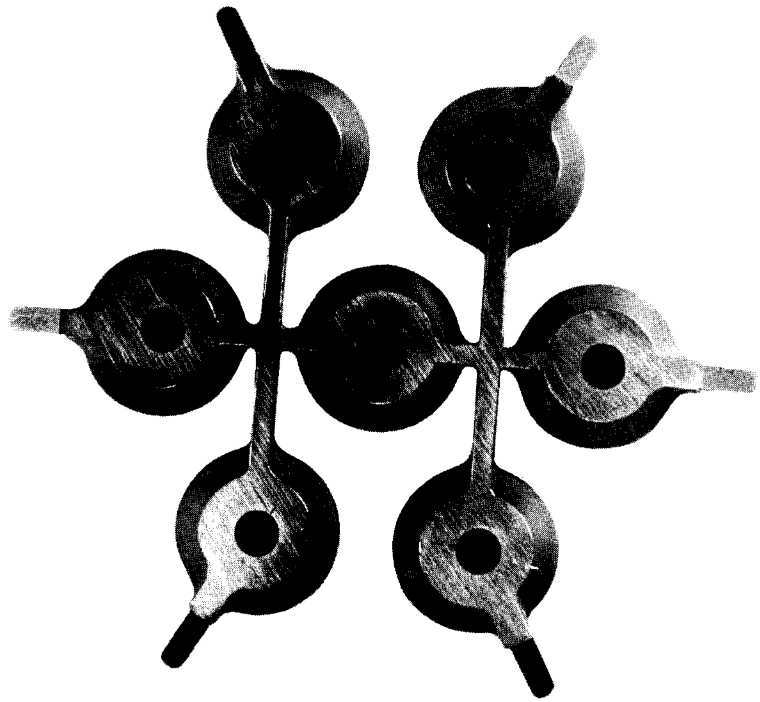
ORNL Photo 48815



Bottom

Fig. 5 Title I Design Top and Bottom Spiders.

and evaluated with two top spiders being rejected. One of these had been labeled as rejected at the manufacturer's plant because of a casting flaw in the outer ring. The second was rejected because of the crack across the rib adjacent to the center boss as shown in Fig. 6. Metallographic sectioning of this crack determined that it was about 1/16 in. deep.

Acceptable radiographic techniques were established for both top and bottom spiders. Standard 2% sensitivity in a single exposure was readily achieved on all portions with the exception of the thin outer ring of the top spider. The scattered radiation superimposed on the image of the thin cross-sectional area reduced the sensitivity to about 4%. A few areas of small porosity were detected and accepted as being nondetrimental. Fifty-six bottom spiders and ninety-five of the top spiders were radiographed with no rejection being made.

CAPSULE CLOSURE WELDS

The inspection techniques developed and applied to the fuel-capsule closure welds included helium leak testing, fluorescent penetrants, and radiography. Initially, each inspection was applied to the first closure weld before any further fabrication was accomplished on the capsule. However, because of the good quality of the welds and to avoid delays in the fabrication schedule, it was decided to examine both closure welds after loading of the capsule.

Helium Leak Testing

The helium leak test was conducted in accordance with Spec. No. RMIS-8(ref 10) with one modification. This involved checking the instrument calibration for each inspection rather than an indefinite interval not to exceed eight hours. This change will be made an integral part of the written procedure. The reference-standard leak had a rate of 7×10^{-9} std cc/sec. The procedure required the indication from the standard to be at least twice that of the background noise. Any through-leak in a capsule which produced an indication twice that of the background was considered to be rejectable.

[10] "Procedure Specification for Helium Leak Testing of Gas-Cooled Reactor Fuel Capsules," Spec. No. RMIS-8, Appendix B of this report.

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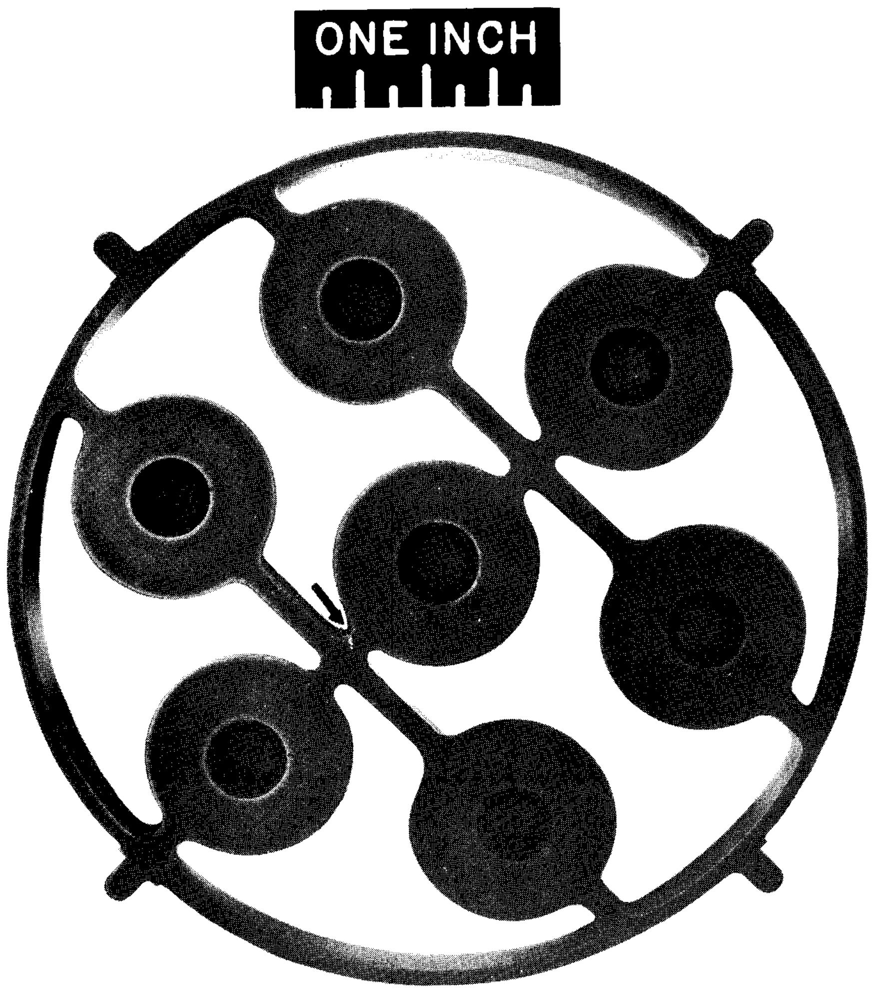

Fig. 6 Black-Light Photograph of Crack in Top Spider.

Two of the approx 350 capsules (700 welds) were found to present indications which were of rejectable size.

Penetrant Inspection

The fluorescent-penetrant technique was used to detect those discontinuities which extended to the outer surface but did not completely penetrate the weld. The materials used were the ZL-1A penetrant and the ZP-4 developer. The technique included precleaning by vapor degreasing, a penetrant soak for 30 min, a wash in a lukewarm-water spray for about 15 sec, drying, 15 min development, and examination under a 100-w black-light source. Similar to the inspection of the spiders, the wash time is one of the most critical portions of the technique. Every penetrant indication of a discontinuity was evaluated by physical removal of the flaw. Any flaw which exceeded a depth of 0.0025 in. was considered cause for rejection. No defects were found which exceeded this tolerance.

Radiographic Inspection

Radiographic inspection was accomplished to detect those subsurface voids which neither connected to the outer surface nor offered a through path for leakage from the interior of the capsule. The possible orientations of the radiation beam and film relative to the weld made the detection of cracks and lack of penetration somewhat impractical. However, it was accomplished to detect porosity and inclusions.

Two radiographic techniques were established and both were used to inspect the closure welds in an attempt to determine which was the optimum. The first technique is illustrated in Fig. 7. The weld is radiographed directly through the 0.200-in.-diam pin of the end cap. The type 304 stainless steel mask, which fits snugly around the cap configuration, increases the total thickness of the metal to 0.250 in. between the radiation source and the weld. The minimum detectable defect size is approx 0.004 to 0.006 in. as limited by the film and other considerations exclusive of the specimen thickness. This minimum size is still attainable through the 0.250-in. mask even though the available subject contrast is decreased. The principal advantage of the mask is that undercut and scatter from the

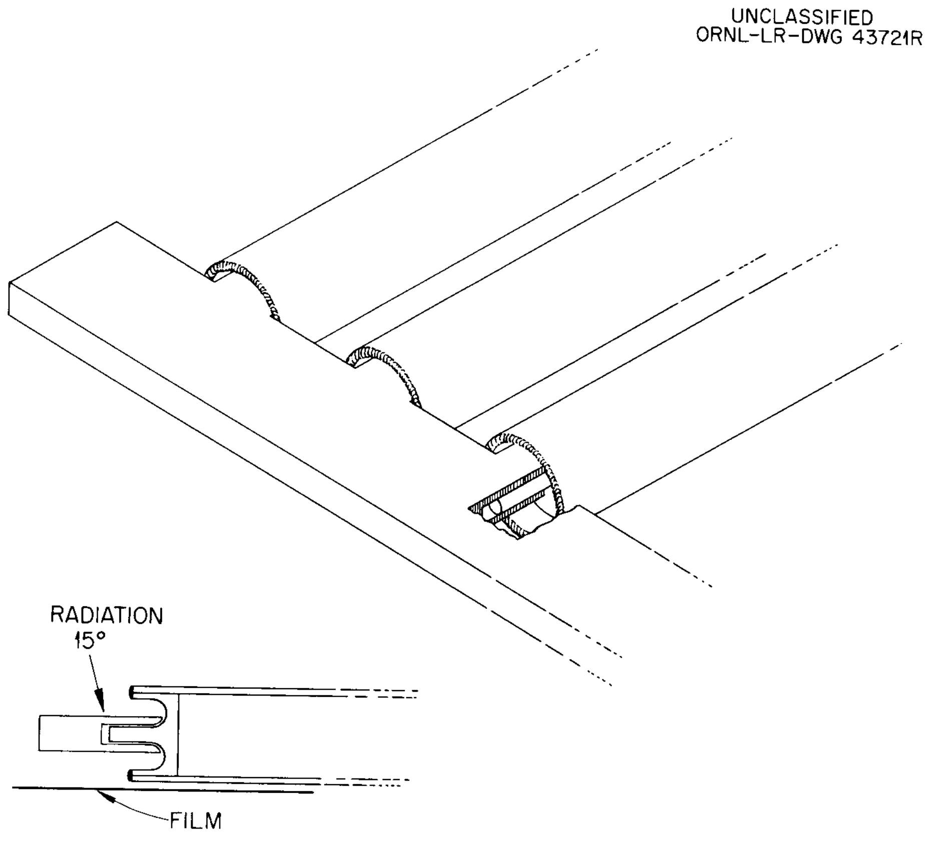

Fig. 7 Masking Technique for the Radiographic Inspection of EGCR Fuel Capsule Closure Welds.

pin is eliminated and a uniform exposure is attained over the portion of the weld being examined. This technique required five exposures around the circumferential weld at 72-deg intervals. The penetrameter which was used was a 0.005-in.-thick shim of type 304 stainless steel containing a 0.005-in.-diam hole. This was placed on the mask and the image of the 0.005-in. hole was plainly visible on all radiographs.

The second radiographic technique is illustrated in Fig. 8. The weld bead is projected slightly with the fuel capsule being inclined at such an angle as to prevent the pin from interfering with the weld image. This technique does offer less specimen thickness with the accompanying advantage of better contrast. However, the minimum detectable defect size is still essentially the same. Some interpretation difficulties were encountered with this technique due to the very small weld image and the rapidly changing thickness through which the radiation passes immediately adjacent to the weld; i.e., the thicker portion of the cap. This technique required four exposures around the circumferential weld at 90-deg intervals. The 0.005-in.-thick penetrameter with the 0.005-in. hole was placed directly on the weld bead and the hole was readily visible on the radiographs.

All of the approx 350 fuel capsules were radiographed with the first technique and about 175 fuel capsules were radiographed by the second technique. With the exception of a few small tungsten inclusions, all of the discontinuities proved to be surface irregularities in the weld, mandrel marks in the tubing, or some other condition external to the weld; and no rejections were made. It was determined that the masking technique was the better for production exposures and interpretation.

GRAPHITE SLEEVE

The most applicable nondestructive test for the graphite sleeves was the eddy-current method. At first it was thought that an encircling circumferential coil for the outer surface and a bobbin circumferential coil for the inner surface would be sufficient for the inspection. This would have necessitated only a single longitudinal scan with each coil. However, experience demonstrated that adequate sensitivity could not be attained by

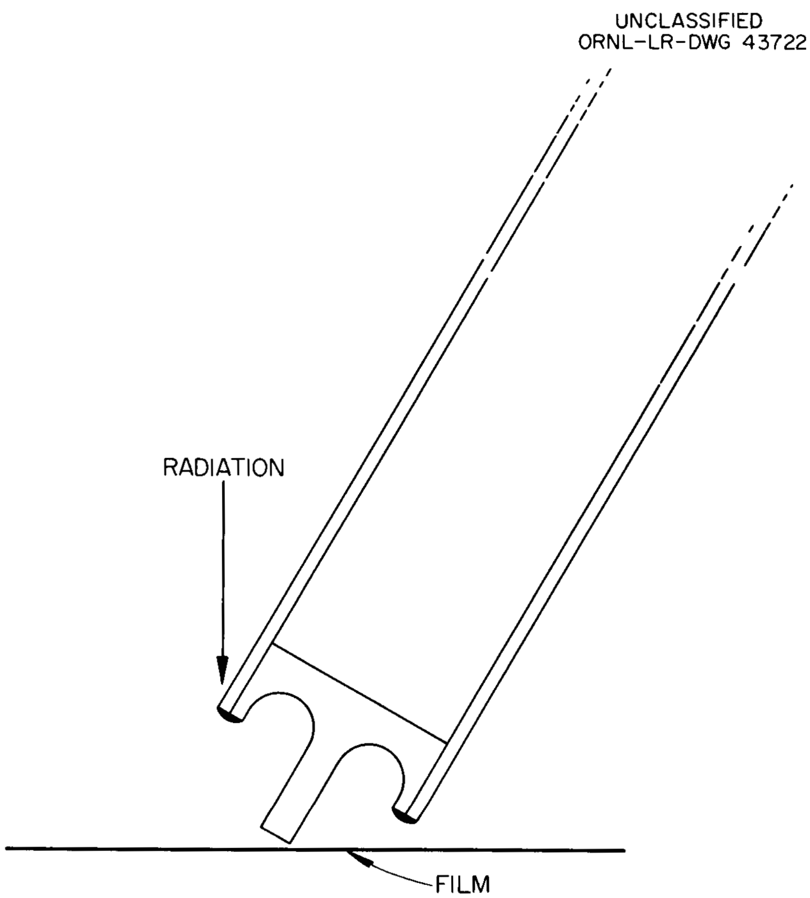

Fig. 8 Alternate Technique for the Radiographic Inspection of EGCR Fuel Capsule Closure Welds.

this technique. An alternate eddy-current technique which proved to be successful incorporates a small probe coil which is placed tangent to the sleeve surface. As the sleeve is rotated, the coil is advanced longitudinally at such a rate as to provide a helical scan along the surface with sufficient overlap to assure 100% inspection. This inspection is accomplished on both the outer and inner surfaces.

The reference discontinuity was a milled notch 0.100 in. deep. Any discontinuity in the inspected graphite sleeves which produced an indication greater than that from the reference notch was considered to be rejectable. Approximately fifty sleeves each from three manufacturers were examined by this technique with rejection rates varying from 34% for the product of one vendor to 92% for the poorest quality batch. Metallographic examination of selected discontinuities revealed the presence of cracks and porous, low-density areas on both inner and outer surfaces. Figure 9 shows the metallographic sections through a crack which extended for most of the sleeve length and the eddy-current indications which were obtained from the crack.

CONCLUSIONS

This pilot plant study on the nondestructive testing techniques for the EGCR fuel element was a vital portion of the inspection development program. Those techniques which had been tentatively proposed were evaluated and modified as necessary. Some of the inspection techniques were completely developed and evaluated during this program. The rather low rejection rate on the components which had received reasonable inspection, in accordance with ORNL requirements, indicates that properly controlled vendor inspection should be adequate to assure integrity. It is believed that technical data are now available for the preparation or modification of inspection specifications which will define the "proper control" on EGCR fuel element components and assemblies. Of course, changes in fuel element design may require minor modifications in some of the specific techniques. However, design changes made to date have not necessitated revisions in the inspection techniques.

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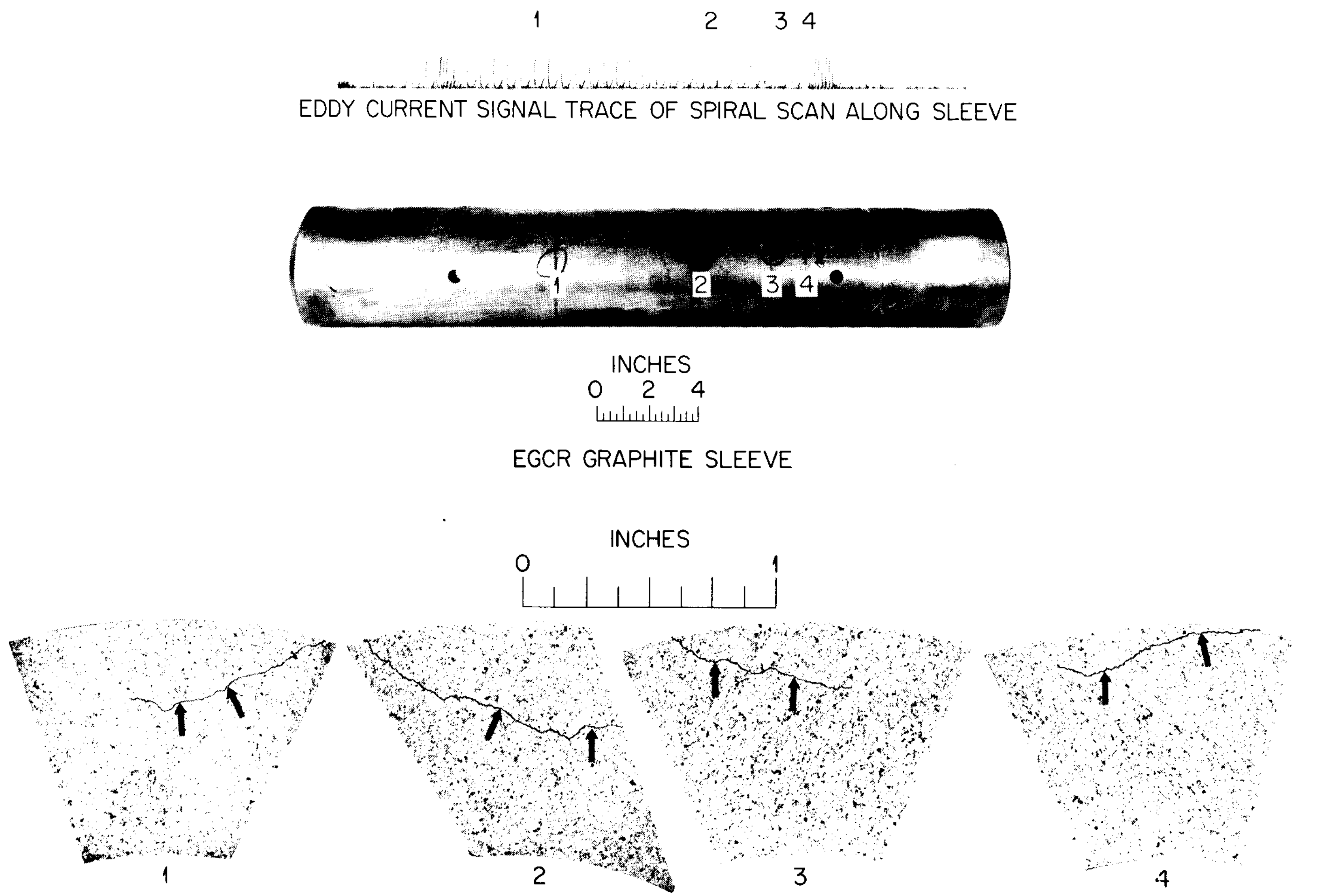

Fig. 9 Eddy-Current Inspection of EGCR Graphite Sleeve. (Photograph retouched to enhance cracking.)

APPENDIX A

REACTOR MATERIAL SPECIFICATION

METALLURGY DIVISION

OAK RIDGE NATIONAL LABORATORY

Union Carbide Nuclear Company
A Division of Union Carbide Corporation
Oak Ridge, Tennessee

Spec No. RMIS-7
Date: August 12, 1958
Revised: August 4, 1959
Page 1 of 4

Subject: PROCEDURE SPECIFICATION FOR THE EDDY-CURRENT INSPECTION OF THIN-WALL AUSTENITIC STAINLESS STEEL TUBING

I. SCOPE: This document specifies the constitution of the approved eddy-current procedure for the inspection of austenitic stainless steel tubing by the tubing manufacturer. This specification applies to the insection of tubing having nominal diameters between and including 1/4 in. and 2 in. and wall thicknesses of 3% or less of the nominal tubing diameter.

II. TECHNICAL REQUIREMENTS:

A. The tubing shall be inspected in random lengths prior to cutting the tubing to the specified lengths. The uninspected ends (ref. Section IV-I of this specification) shall be removed before cutting the finished tubing to the specified lengths.

B. The inspection shall be accomplished by an inspector whose competence is certified by the vendor.

C. The inspection equipment used shall be suitable as described in Section III of this specification.

D. The defective portion of tubing classified "rejected" according to the provisions of Section IV-F of this specification shall be removed prior to cutting the tubing to final length. The defective section shall be marked in such a manner that it is clearly indicated that the defective section has been rejected by the eddy-current inspection. A representative portion of these rejected sections, if any, shall be sent to the Metallurgy Division, Oak Ridge National Laboratory for examination; however, no rejected tubing having lengths of less than 2 ft nor greater than 10 ft shall be sent. This representative portion shall be considered a part of the specified amount on the purchase order, but shall not exceed 100 ft or 10% of the specified amount on the purchase order, whichever is less.

E. The inspection procedure shall be in accordance with Section IV of this specification or by an approved alternate. If an alternate procedure is desired, it shall be submitted to the Metallurgy Division, Oak Ridge National Laboratory for approval.

F. Standardization of the inspection shall be accomplished according to the provisions of Section V of this specification or by an approved alternate. If an alternate standardization is desired, it shall be submitted to the Metallurgy Division, Oak Ridge National Laboratory for approval.

G. The tubing shall be inspected at the completion of the manufacturing process. Any deviation from this shall be submitted to the Metallurgy Division, Oak Ridge National Laboratory for approval.

III. INSPECTION EQUIPMENT:

A. Inspection shall be accomplished using an encircling (feed through) coil system.

B. The mechanism used to drive the tubing through the coil system shall be capable of operating at a constant speed and shall be free from jerking and excessive vibration.

C. The sensitivity of the instrumentation shall be such that the provisions of Section IV can be accomplished.

D. Signals from the inspection equipment shall be displayed in such a manner that the presence of a defect is clearly indicated.

IV. INSPECTION PROCEDURE:

A. A standard reference tube fabricated according to Section V of this specification shall be used to establish the sensitivity and response of the inspection system.

B. The tubing shall be driven through the coil system at a uniform rate of speed. The speed shall be in conformance with the capabilities of the inspection instrumentation and the operator to clearly detect the signal produced by the standard defect in the standard reference tube.

C. The equipment shall be adjusted in such a manner that a clear indication of the presence of the standard defect in the reference tube is obtained.

Subject: PROCEDURE SPECIFICATION FOR THE EDDY-CURRENT INSPECTION OF THIN-WALL AUSTENITIC STAINLESS STEEL TUBING

D. The operating frequency of the instrument shall be chosen as low as possible, consistent with the reliable detection of the standard defect, but the frequency shall not exceed the maximum frequency calculated by the following formula:

$$F_{max} = \frac{36.5}{D^2}\ \text{kc}$$

where F = Frequency (kc)
D = Nominal Tubing Diameter (inches).

E. The standard reference tube shall be used periodically to check the performance of the inspection. If at any time the equipment fails to produce a clear indication of the presence of the standard defect, the equipment shall be readjusted to give a clear indication, and all tubing which has been inspected during the interim since the last satisfactory standardization shall be inspected again.

F. Any portion of the tubing which produces an indication as large or larger than the average indication produced by the standard notches in the standard reference tube as defined in Section V-D shall be classified as rejected.

G. If a phase detector is being utilized in the inspection equipment, the phase control shall be adjusted such that a phase shift of 10 degrees in either direction from the operational setting will not reduce the size of the indication from the standard defect more than 15%.

H. The tubing shall be inspected by feeding it through the coil system in the direction which produces the most sensitive inspection.

I. A test shall be devised by the vendor to determine the length of the uninspected ends of the tubing.

V. STANDARD REFERENCE TUBE:

A. Standard reference tubes shall be fabricated from tubing taken from the same heat and manufactured by the same processes as the tubing to be inspected.

B. Standard reference tubes shall be approximately 5 ft long.

Subject: PROCEDURE SPECIFICATION FOR THE EDDY-CURRENT INSPECTION OF THIN-WALL AUSTENITIC STAINLESS STEEL TUBING

C. Transverse notches shall be cut on the outside surface of the tube at approximately 3 in. intervals along the tube beginning 6 in. from each end of the tube. The notches shall be cut with a calibrated file notching tool containing a 1/4 in. round file and which is capable of accurately controlling the depth of cut. The filed notch shall have a depth of 12.5% of the wall thickness. The axis of the file shall be held perpendicular to the axis of the tube and shall not traverse along the tube during the cutting operation. The axis of the file shall not be allowed to rotate about the axis of the tube nor shall the tube be allowed to rotate about its own axis during the cutting operation.

D. The standard reference tube shall be examined with the eddy-current equipment. The average signal produced by the filed notches shall be determined and the depth of one of these notches which produces a signal equal to or greater than the average notch signal shall be accurately measured. If the depth of this notch is not greater than 12.5% of the wall thickness, the tube may be used as the standard reference tube for calibrating the eddy-current equipment.

E. Any defect indication which may be present in the standard reference tube shall not be allowed to interfere with the identity or evaluation of the standard defects.

F. The standard reference tube shall be examined visually in the region of the standard defect to determine any damage to the tube as a result of the filing operation. The tubing shall be free of scores, dents, burrs, and other marks in the region of the standard defect.

G. Upon completion of the entire inspection, the standard reference tube shall be sent to the Metallurgy Division, Oak Ridge National Laboratory. This tube shall be considered a part of the specified amount on the purchase order.

APPENDIX B

REACTOR MATERIAL SPECIFICATION
METALLURGY DIVISION
OAK RIDGE NATIONAL LABORATORY

Spec No. RMIS 8
Date: August 6, 1959
Revised: October 13, 1959

Union Carbide Nuclear Company
A Division of Union Carbide Corporation
Oak Ridge, Tennessee

Subject: PROCEDURE SPECIFICATION FOR HELIUM LEAK TESTING OF GAS-COOLED REACTOR FUEL CAPSULES

I. SCOPE: This specification applies to the envelope method of helium leak testing the first closure weld before assembly and to the bell jar method of testing the assembled, helium-containing fuel capsules after the final closure weld has been accomplished.

II. REFERENCE: The manufacturer's operating manual for the particular instrument used in the inspection.

III. EQUIPMENT:

A. A mass spectrograph type, helium-sensitive instrument, similar to the Veeco-Type MS-9 or Consolidated Engineering Corporation Type 24-110, which includes the following as incorporated in the instrument or as additions or modifications:

1. A cold trap (liquid nitrogen or liquid air).
2. A helium leak source of 7×10^{-9} std cc/sec.
3. An external or auxiliary roughing vacuum pump connected to the instrument manifold and to the specimen or test chamber through a vacuum valve.
4. A throttling or modulating valve between the instrument manifold and the instrument.

B. A low pressure supply of helium with a nozzle less than 1/16 in. in diameter for use in checking for leak-tight connections.

C. One or more leak-tight chambers, each of which is capable of accommodating a fuel capsule for the final closure weld inspection and having no less than 3/8 in. diametral clearance between the fuel capsule and the wall of the chamber.

D. An envelope capable of surrounding the capsule with an atmosphere of helium for the inspection of the first closure weld.

IV. TECHNICAL REQUIREMENTS:

A. The instrument sensitivity shall be such that the stable signal from the standard leak, as determined in Section V-C-1&2 of this specification, is at least two times as large as the signals produced by background noise.

Subject: PROCEDURE SPECIFICATION FOR HELIUM LEAK TESTING OF GAS-COOLED REACTOR FUEL CAPSULES

B. The inspection shall be accomplished by an inspector whose competence is certified by the agency inspecting the fuel capsules.

C. The inspection chamber used in the bell jar inspection technique shall be thoroughly purged with a suitable gas after each inspection to insure the smallest possible helium background.

D. The inspection shall be performed in a force-ventilated location to facilitate the removal of any helium background.

E. The connecting lines between the test chamber and the instrument manifold shall be as short as is practical and should have a minimum inside diameter of 1/2 in. All connections shall be leak-tight.

F. Care shall be exercised to avoid plugging leaks with any sealant prior to attempted detection with helium.

G. All assembled fuel capsules shall be either helium leak tested within 24 hours after the final closure weld is completed or stored in a helium atmosphere until such time as they can be helium leak tested. If a fuel capsule is to be retested or if the testing procedure is interrupted, as in Sections V-A, V-F, and V-G, the capsule shall be stored in a helium atmosphere until such time as testing can be completed. No assembled fuel capsule shall be allowed to remain in a non-helium atmosphere for more than a total of 48 hours between the time of its assembly and the completion of helium leak testing.

V. TESTING PROCEDURE:

A. The performance of the leak detector equipment shall be verified periodically (at least once each 8 hr. shift). If at any time this equipment fails to function properly as described in the manufacturer's operating manual and/or if the sensitivity as determined in Section V-C of this specification decreases below the minimum level prescribed in Section IV-A the equipment shall be readjusted to function properly and recalibrated, and all fuel capsules which have been inspected during the interim since the last satisfactory performance verification of the equipment shall be inspected again.

B. The closure welds shall be inspected as follows:

1. The initial closure weld shall be inspected by connecting the open end of the capsule tubing to the manifold of the leak detector and by placing the capsule tubing in an envelope of helium at atmospheric pressure. The search for leaks shall be made as prescribed in the instrument manufacturer's operating manual.

2. The assembled, helium-containing fuel capsules shall be inspected after the final closure weld has been accomplished by placing the fuel capsule in the inspection chamber, evacuating the chamber, and searching for helium leaks as prescribed in the instrument manufacturer's operating manual.

C. The instrument shall be calibrated as follows:

1. Envelope method.

The standard leak source (7×10^{-9} std cc/sec) shall be connected to the manifold. The time which is required to produce a signal at least two times as large as the background noise shall be measured. This measurement shall be accomplished while examining a 100% sample from the capsule tubing and with all valves between the capsule and the helium-sensing device completely open. This portion of the calibration shall be continued until the signal from the standard leak reaches a stable amplitude and manifold pressure shall be measured at this point.

2. Bell jar method.

The standard leak source (7×10^{-9} std cc/sec) shall be connected to one end of the test chamber. The opposite end of the test chamber shall be connected to the manifold and the time which is required to produce a signal two times as large as the background noise shall be measured. This measurement shall be accomplished while examining a 100% sample from the test chamber and with all valves between the standard leak source and the helium-sensing device completely open. This portion of the calibration shall be continued until the signal from the standard leak reaches a stable amplitude. The signal amplitude and manifold pressure shall be measured at this point.

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D. The inspection shall be made taking a 100% sample from either the interior of the capsule tubing or the test chamber depending upon which of the two methods is used. All valves between the capsule and the helium-sensing device shall be completely open and the time of inspection shall be no less than one minute and at least twice as long as that time (determined in Section V-C of this specification for that particular method) required for the standard leak to produce a signal two times as large as the background noise.

E. The manifold pressure at which the inspection is made shall be the same as the pressure at which the instrument is calibrated as measured in Section V-C of this specification for the particular method used.

F. Excessive pump-down time shall be indicative of an external leak. The leak shall be located and corrected before further testing is accomplished.

G. During the inspection any signal which produces an indication two times as large as the background noise level shall be indicative of a through path or leak in the capsule being inspected and that fuel capsule shall be rejected. If more than one assembled fuel capsule is being inspected at the time a leak is detected, the capsules shall be inspected again such that the leaking capsule or capsules are identified and rejected.

H. All rejected, assembled, helium-containing fuel capsules shall be disassembled. Any salvable parts of the rejected fuel capsules may be reused in the assembly of other capsules.

I. Any rejected first closure weld may be recycled through the welding process unless there are obvious defects which would hot be corrected by such a recycle. If a rejected first closure weld is rewelded, any inspection which may have been accomplished between the time of the first welding and the rejection by helium leak testing shall be repeated.

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