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ISOTOPE KILOWATT PROGRAM FUEL CAPSULE TESTING

N. C. Bradley

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ISOTOPES DEVELOPMENT CENTER

ISOTOPE KILOWATT PROGRAM FUEL CAPSULE TESTING

N. C. Bradley

Isotopes Division

OCTOBER 1973

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CONTENTS

Page

ABSTRACT 1

SUMMARY 1

CAPSULE DESCRIPTION 2

CAPSULE FABRICATION 3

CAPSULE TESTING 5

CONCLUSION 10

REFERENCES 11

APPENDIX I — Test Procedures and Data Sheets 12

APPENDIX II — Dimensional Inspection Reports 37

APPENDIX III — Figures of IKP Capsule 52

APPENDIX IV — Fabrication Check Sheets 87

ISOTOPE KILOWATT PROGRAM FUEL CAPSULE TESTING

N. C. Bradley

ABSTRACT

Two large heat source capsules designed for the Isotope Kilowatt Program were fabricated and loaded with inert strontium titanate and subjected to a series of tests to determine if the capsules met the IAEA Safety Series No. 33 containment criteria for radioisotope heat sources to be used for terrestrial and undersea electric power generators. The capsules met all test conditions with the exception of the free drop test upon the capsule top cap end. This end can be redesigned to be identical with the bottom end which did withstand the free drop test.

SUMMARY

Two inactively fueled capsules were fabricated to the design specifications for radioactive $^{90}SrTiO_3$ fueled capsules for the Isotope Kilowatt Program and were submitted to a series of tests designed to test the capability of the capsule to meet the requirements for integrity of containment for the radioactive fuel as specified in IAEA Safety Series No. 33 and No. 6, USAEC regulations, and USDOT regulations.

The capsule was designed[1] to contain the fuel without leakage (1) when in seawater at a pressure of 10,000 psi for a 300-year period, (2) when in a 1-hr fire, (3) when dropped up to 30 ft onto an unyielding surface, (4) when a heavy blunt-pointed object is dropped upon the capsule, and (5) when the thermally hot capsule is dropped into a cold medium.

The capsule design was such that the yield strength would not be exceeded when subjected to a hydrostatic pressure of 10,000 psi and was determined to be adequate to meet the IAEA Safety Series No. 33 requirement of a 14,500-psi hydrostatic test with only minor capsule deformation, but leak tightness.

The capsules were fabricated in the ORNL machine shops from Hastelloy C-276 and were 4.100 in. OD by 40.400 in. long (Fig. 1). They were each fueled with approximately 56 lb of inert $SrTiO_3$ pellets that were 3.4 in. in diameter by 1.2 to 2.0 in. thick (Fig. 2). The bottom of the capsule was sealed by a 0.780-in.-thick cap welded by an electron-beam welder. The top cap was screwed into the capsule and seal welded using a plasma arc welder. The finished capsules were dimensionally inspected and vacuum leak tested in ethylene glycol. The capsules were subjected to a preconditioning heat treatment at 1600°F for 1 hr in argon prior

to being tested to ensure that the Hastelloy C-276 would be metallurgically similar to a thermally hot, fueled capsule.

The testing program was conducted using both capsules for a different set of tests as follows:

Capsule No. 1	Hydrostatic Test Immersion Test Vibration Test
Capsule No. 2	Heating Test Thermal Shock Test Free Drop Test, Top End Free Drop Test, Bottom End Percussion Test

The capsules were dimensionally inspected, leak tested, and photographed prior to and following each test. The test procedures and data sheets are in Appendix I, the dimensional inspection reports in Appendix II, and the photographs in Appendix III.

The capsules successfully passed all tests with the exception of the free drop test upon the capsule's top edge. The capsule wall in the threaded area deformed allowing the capsule threads to lose contact; the shoulder deformed, and the seal weld sheared. A hairline crack approximately 2-in. long opened at the top giving a gross leak rate. The free drop upon the electron-beam-welded bottom cap held, and this design can be used for the top closure. The hydrostatic test to 14,505 psi is the only other test that deformed the capsule to any significant extent, and this was a small amount of swaging or wrinkling of the capsule.

CAPSULE DESCRIPTION

Two inactively fueled capsules have been fabricated to design specifications[1] and tested for the capability to meet the requirements of 10 CFR 71 (ref. 2), IAEA Safety Series No. 6 (ref. 3), and IAEA Safety Series No. 33 (ref. 4).

The capsule for the Isotope Kilowatt Program is designed for complete containment of the fuel in seawater at pressures up to 10,000 psi (equivalent to 22,500-ft depth of seawater with a density of 64 lb/ft^3) without exceeding its yield point at operating temperatures for 300 years and under conditions of a 1-hr fire test as prescribed in the code of the National Fire Protection Association. Much broader design requirements were imposed to ensure containment of the fuel under "maximum credible accident" situations.

The fuel capsule, shown in Fig. 1, is a right circular cylinder, 4.100 in. in diameter by 40.400 in. overall length with a wall thickness of 0.325 in., and will contain approximately 4860 W_{th} of $^{90}SrTiO_3$. This wall thickness

includes an allowance of 0.030 in. to provide for seawater corrosion for a 300-year period using a rate of 10^{-4} in./year for Hastelloy C-276. The corrosion rate also governs the depth of penetration of the seal weld on the top cap (0.055 in.) and the structural weld on the bottom cap (0.120 in.). To reduce shear stress on the bottom welded joint and the top threaded joint, the top and bottom caps rest on shoulders machined into the cylindrical body of the capsule. These shoulders are 0.073 in. and 0.045 in. wide for the top and bottom, respectively. The top and bottom caps are raised 0.060 in. above the weld areas so that the weld bead will not interfere with assembly of the capsule into the heat block or cask and so that the overall length of the capsule is accurately known.

The bottom cap of both capsules had four holes drilled and tapped for use in handling. Three 120° spaced holes were used for handling during the ultrasonic inspection of the bottom cap weld. The fourth hole was spaced 180° as those in the top cap to facilitate handling the capsules during the testing program. These extra tapped holes will not be required in a fueled capsule.

CAPSULE FABRICATION

The Hastelloy C-276 material for the fabrication of the capsules was purchased from Atek Metals Center, Inc. The chemical analysis and mechanical properties test results for the material are given in Appendix IV. The bottom caps were machined from the 1-in.-thick plate, the top caps were machined from the 2-in.-thick plate, and the cylindrical body was machined from the 4-1/2-in.-diam rod.

The finished parts for the capsules were dimensionally inspected by the ORNL Mechanical Inspection Department, and the results are shown in Appendix IV (Fig. 62). Capsule No. 1 parts were machined first and some design tolerances were exceeded. It was decided that these dimensional differences would not change the capsule strength significantly; therefore, the capsule was used in the testing program. Capsule No. 2 was machined second with improvements in the machining techniques which resulted in only one minor exception of a surface finish tolerance. The cylindrical body of Capsule No. 1 was found to exceed design tolerances as follows:

1. Overall length (40.280 in.) exceeded by 0.010 in.
2. Top cap shoulder depth (1.062 in.) exceeded by 0.014 in.
3. Bottom end ID (3.540 in.) exceeded by 0.005 in.
4. Total indicated runout of the ID (±0.003 in.) exceeded by 0.010 in.
5. Inner surface finish found to be 350 μin.
6. Capsule ID (3.450 in.) undersized by 0.0065 in.

The top cap of capsule No. 1 exceeds the design dimensions on the weld shoulder thickness (1.000 in.) by 0.0096 in. The bottom cap of capsule

No. 1 was within tolerances. The only exception to the design measurements for capsule No. 2 parts was a 65-μin. finish on the ID of the cylindrical body.

The bottom caps were welded into the capsule bodies using a large Sciaky electron-beam welder using the following parameters:

1.	Beam voltage	40 kV
2.	Beam current	100 ma
3.	Weld speed	33 in./min
4.	Sharp focus	410
5.	Weld focus	+10
6.	Gun to work distance	9-1/32 in.
7.	Chamber pressure	5×10^{-5} mm Hg

These settings gave a weld penetration of 0.312 in. and a mid-width of 0.0625 in. with test specimens. Macrophotographs of a section from capsule No. 2 bottom weld are shown in Fig. 3.

The bottom end cap to capsule body welds for both capsules were ultrasonically inspected using commercial ultrasonic instrumentation and a 15-MHZ tranducer. The recordings from the transducer measurements of the weld area are shown on pp. 101-6 in Appendix IV. Capsule No. 1 was measured to have a maximum weld penetration of 0.428 in. and was found to meet the weld requirements.[1] Capsule No. 2 was measured to have a maximum weld penetration of 0.360 in.; however, a hole was detected near the outer edge with a magnitude of 0.030 to 0.040 in. in length. Because the indication of the hole was borderline and the maximum penetration was three times that required, the weld was considered acceptable.

The capsules were fueled with inactive $SrTiO_3$ fuel pellets which did not contain the nickel screens as described in the design report and which varied in thickness. The nickel screens were not used because the screens were only used to aid in heat transfer and not in pellet strength and also the cold-pressed pellet sintering temperature was equal to the melting point of nickel. The fuel pellets varied widely in thickness because the assortment of pellets fabricated during a study of first hot-pressing and then cold-pressing methods was used to fuel the capsules. The main criteria for good inactive fuel pellets was good density, solid pellets, and proper diameter.

The major portion of the inactive $SrTiO_3$ fuel pellets were fabricated in the following manner. Strontium carbonate and titanium dioxide were co-precipitated in 100-liter batches. The precipitate was filtered, dried, and calcined at 1250°C for 8 hr. The calcined powder was then blended to a fine powder with a Waring blender. The powder was then cold-pressed at 4800 psi for 10 min in a steel die body. The extruded pellets were about 4-1/4 in. in diameter and 1-1/2 to 2-1/2 in. high depending on the amount of powder used. The pellets were sintered at 1450°C for 8 hr; the pellet was reduced 20% in size.

The pellets were measured and placed into two stacks ∿38.4 in. high and then loaded into the capsules. Capsule No. 1 weighed 54.40 lb and was loaded with 54.75 lb of $SrTiO_3$ pellets. Capsule No. 2 weighed 54.50 lb and was loaded with 56.50 lb of $SrTiO_3$ pellets. Figure 2 shows one of the capsules and pellets prior to assembly.

The top caps were installed and seal welded using a plasma arc torch. The Thermal Dynamics plasma arc torch was programed to start on a 10-amp current for 30 sec, go to 110 amp in 1 sec and weld for 74 sec at a weld speed of 10 in./min, and then decrease to 10-amp current in 4 sec. The torch was set 5/16 in. from the weld and used a 3/32-in. orifice with 1.85 ft^3/hr argon plasma gas and 10 ft^3/hr argon-4% hydrogen shield gas. Test welds using these parameters gave a penetration of approximately 0.080 in. Pretest welds are shown in Figs. 4 and 5. Figure 6 is a macrophotograph of capsule No. 2 top cap weld in the section that was not affected by the free drop test.

Figures 7, 8, and 9 show the side, bottom, and top views of the completed capsule No. 1; Figs. 10, 11, and 12 show views of capsule No. 2.

CAPSULE TESTING

The Capsule Testing Program was conducted using the two capsules in the following order:

Capsule No. 1	Hydrostatic Pressure Test Immersion Test Vibration Test
Capsule No. 2	Heating Test Thermal Shock Test Free Drop Test, Top End Free Drop Test, Bottom End Percussion Test

The test procedures and completed check lists are found in Appendix I.

This phase of the program requires that the capsules be photographed, dimensionally inspected, and leak tested prior to and subsequent to each test. The capsules were photographed in three views (top, side, and bottom) each time, with additional photographs of specific affected areas as needed. The dimensional inspections of the capsules were made by the Mechanical Inspections Department, and the data sheets are to be found in Appendix II. Table 1 gives the dimensions of capsule No. 1 and capsule No. 2 in a form for easy comparison of the deformation caused by the tests. The leak tests of the capsules were done by vacuum leak testing in ethylene glycol. This type test will detect leaks as small as $\sim 4 \times 10^{-6}$ atm cm^3/sec. The leak test procedure and a discussion of leak testing are included in Appendix I. The leak testing equipment is shown in Fig. 13 and a close-up of a negative test of capsule No. 2 top is shown in Fig. 14.

Table 1. Dimensional Inspection Results[a]

Test Condition	Top (in.)		Middle (in.)		Bottom (in.)		Length (in.)	Total Indicated Runout (in.)				Paral-lelism (in.)	Perpendicularity (in.)	
	Largest	Smallest	Largest	Smallest	Largest	Smallest		0°	90°	180°	270°		Top	Bottom
Capsule No. 1														
Design	4.100 ± 0.002		4.100 ± 0.002		4.100 ± 0.002		40.400 ± 0.005	±0.003	±0.003	±0.003	±0.003	±0.005	±0.005	±0.005
Initial	4.1009	4.1005	4.1010	4.1010	4.0998	4.0982	40.413	0.0027	0.0025	0.0030	0.0010		0.007	0.004
Anneal	4.0998	4.099	4.1003	4.100	4.0988	4.0976	40.402	0.003	0.0025	0.003	0.0023	0.005	0.007	0.003
Hydrostatic	4.110	4.100	4.110	3.960	4.087	4.078	40.329	0.095	0.020	0.005	0.010	0.012	0.007	0.012
Immersion	4.109	4.100	4.109	3.959	4.087	4.079	40.329	0.083	0.034	0.029	0.023	0.012	0.007	0.013
Vibration	4.106	4.101	4.107	3.962	4.095	4.080	40.323	0.053	0.140	0.086	0.117	0.010	0.007	0.011
Capsule No. 2														
Design	4.100 ± 0.002		4.100 ± 0.002		4.100 ± 0.002		40.400 ± 0.005	±0.003	±0.003	±0.003	±0.003	±0.005	±0.005	±0.005
Initial	4.1009	4.0996	4.1010	4.1009	4.1015	4.1002	40.420	0.002	0.002	0.002	0.0023	0.010	0.001	0.012
Anneal	4.0994	4.0984	4.1001	4.0999	4.1013	4.0999	40.405	0.002	0.0015	0.003	0.002	0.011	0.002	0.015
Heat Test	4.0991	4.0981	4.0997	4.0995	4.1009	4.0993	40.408	0.002	0.003	0.0025	0.003	0.0115	0.002	0.014
Thermal Shock	4.116	4.016	4.106	4.0892	4.1077	4.105	40.426	0.010	0.005	0.011	0.009	0.017	0.002	0.017
30-ft Drop Top End	4.229	4.195	4.105	4.097	4.106	4.105	40.3305	0.030	0.090	0.150	0.025	0.213	0.213	0.012
30-ft Drop Bottom End	4.224	4.195	4.104	4.097	4.159	4.151	40.330	0.065	0.117	0.125	0.060	13/32	7/32	3/16
Percussion	4.195	4.160	4.106	4.095	4.158	4.152	40.359	0.00	0.135	0.165	0.040	0.475	0.210	0.160

[a]Dimensions indicated are those taken after the indicated test; each set serves as the pretest dimensions for the following test.

The completed capsules were dimensionally inspected; capsule No. 1 was found to exceed the design length of 40.400 in. by 0.013 in. and the top cap was out of perpendicularity by 0.007 in. Capsule No. 2 exceeded the design length by 0.020 in., parallelism by 0.010 in., and the bottom cap perpendicularity by 0.012 in.

Photographs of capsule No. 1 are shown in Figs. 7, 8, and 9 and of capsule No. 2 in Figs. 10, 11, and 12. The vacuum leak tests of both capsules did not indicate any leaks.

The capsules were subjected to a preconditioning heat treatment prior to testing to ensure that the metallurgical condition of the Hastelloy C-276 would be representative of an actual capsule after being exposed to an operating environment. This heat treatment was conducted by heating the capsules in a furnace at 1600°F for 1 hr in an argon atmosphere, then removing the capsule, and allowing it to air cool.

Both capsules were again dimensionally inspected, and a shortening of the capsule lengths by 0.011 in. and 0.015 in. for capsule No. 1 and No. 2, respectively, was noted. The leak tests did not indicate any leaks. Photographs of capsule No. 1 are shown in Figs. 15, 16, and 17 and capsule No. 2 in Figs. 18, 19, and 20. Capsule No. 1 was packaged in a shipping box and sent to the Naval Ship Research and Development Center, Bethesda, Maryland, for hydrostatic testing.

The capsule successfully withstood the hydrostatic test in which pressure was applied in progressive 1000-psig increments up to 14,505 psig and then released in 1000-psig increments down to zero. However, the capsule did show some wrinkling or swaging, with the most pronounced effect near the top end of the capsule. The diameter of the capsule changed as much as 0.140 in., the length shortened by 0.073 in., and the total indicated run-out was as great as 0.095 in. The vacuum leak test of the capsule did not show a leak. The effect of the pressure upon the capsule is shown in photographs in Figs. 21 through 26. The pressure test data and dimensional inspection data reported by the Navy[5] are reported in Appendices I and II, respectively.

Capsule No. 1 was then submitted to an immersion test in 3 ft, 4 in. of water for 72 hr. This exceeded the test requirements of 2 ft of water above the capsule for 24 hr. No leaks were found and there was no detectable change in the capsule. Figures 27, 28, and 29 are photographs of the capsule after the test.

Capsule No. 1 was next submitted to the vibration test. The test equipment is shown in Figs. 30 and 31, and the test procedure is given in Appendix I. The vibration testing equipment was a MB Electronics unit capable of exerting up to 550 force pound to the capsule over a frequency range of 5 to 3000 cycles/sec. This is below the 5000 cycles/sec quoted in the test procedure due to a misunderstanding in the original inquiry to the machine owner. The capsule was fastened to the exciter by an adapter, which was flanged to the exciter table and connected to a pinned collar fastened to the center of the capsule. The capsule was suspended

vertically by a cable to an overhead steel support. The capsule was vibrated through the 5- to 3000-cycle/sec range at a preset automatic controlled 0.2-G force loading and scanned for resonant peaks using a separate accelerometer and readout connected to the collar clamping the capsule. Five resonant frequencies (385, 810, 1140, 2550, and 3000 Hz) were detected. The capsule was vibrated at each frequency at a force of 1, 2, 3, 4, and 5 G for 30 min at each level. The data sheets are found in Appendix I. No leaks were detected in the capsule at the conclusion of the test. Photographs of the capsule are shown in Figs. 32, 33, and 34.

The dimensional inspection showed a small increase (up to 0.140 in.) in the total indicated runout. In this test the total force was applied to the center of the capsule with the ends being totally unrestrained, thus, a slight bowing of the capsule resulted. This small change would not be expected in a capsule that is constrained within a generator shield.

Prior to the testing of capsule No. 2, a 110-lb steel cylinder was heated in the clamshell furnace to determine the heat-up rate and also to determine an approximate air cool-down rate for the capsule. Two thermocouples were attached to the test piece. One was spot-welded to the outside diameter of the piece, 1 in. from the end. The other thermocouple was inserted into a 1/8-in.-diam hole drilled 1 in. deep, 1/8 in. below the cylinder's outside diameter surface. The capsule was heated to 855°C, quickly removed from the furnace, and placed upon four large fire bricks turned on their edges to allow good air circulation for cooling. Figure 35 is a graph of the cool-down rate which shows, as expected, that the outer surface temperature cools much faster than the metal at a depth of 1/8 in. below the surface. This sub-surface temperature would more likely represent the true temperature of the capsule at the time of the test. Because it was not feasible to place a thermocouple within the capsule during testing, a thermocouple was loosely fastened to the outer surface by two wires, so that the thermocouple could be easily pulled loose during the drop tests. The thermocouple did measure the capsule temperature inside the furnace, but during the removal of the capsule from the furnace, the thermocouple moved from surface contact and no accurate temperatures were recorded after removal.

Capsule No. 2 was first submitted to a heating test. The capsule was placed into the clamshell furnace and heated to 800°C for 30 min. The furnace was then turned off and opened so that the furnace and capsule could air cool to room temperature. There was no significant dimensional change and the vacuum leak test indicated that no leaks existed. Post-test photographs of the capsule are shown in Figs. 36, 37, and 38.

Capsule No. 2 was next submitted to the thermal shock test. The capsule was heated to 800°C for 1 hr and then plunged into a 450 gal ice-water bath cooled to 1/2°C. The stirred bath increased to 2°C after 25 min and remained at this temperature for the remainder of the hour. The dimensional inspection showed a small 0.006- to 0.017-in. general increase in diameter, an 0.018-in. increase in length, and an increase in the total indicated runout of up to 0.009 in. The vacuum leak test did not indicate any leaks. Post-test photographs of the capsule are shown in Figs. 39, 40, and 41.

Capsule No. 2 was next submitted to a free drop impact test upon the plasma-arc seal-welded top-end edge. The test requires that the capsule (1) be heated to 800°C, (2) be dropped so that the capsule center of gravity is directly above the capsule edge at impact, (3) be free dropped for a distance of 30 ft, and (4) be impacted upon a flat unyielding surface.

The test was set up and conducted as follows. A clamshell furnace was mounted vertically on top of a 40-ft-tall steel drop tower. The capsule was pulled up into and held in the furnace by a steel cable which was hooked into a ring fastened to the end of the capsule. The ends of the furnace were covered by asbestos and fire brick to prevent a cooling chimney effect on the furnace. A trough-like chute was fastened to the bottom of the furnace to direct the hot capsule down to a drop cradle. The drop cradle had two angle-iron edges to support the capsule at an 8° angle from the vertical. The capsule's weight was supported by a toe plate at 180° from the impact edge. The drop cradle was guided down the drop track by four loose fitting nylon guides. The impact point was a steel pad, 4 × 4 × 1/4 in., welded to the steel tower floor which was set into a thick concrete base extending to bedrock that supported the tower. The drop distance from the cradle bottom down to the impact pad was measured to be 30 ft 0 in. on the original setup using a mechanical drop release mechanism. A last minute change to a newly designed hydraulically operated quick release mechanism led to the drop distance being inadvertently decreased to 29 ft 7 in. (9.02 m). This distance does not meet the 30-ft requirement of this test procedure but does meet the 9.0-meter distance set forth in the IAEA Safety Series No. 33.

The capsule was heated in the furnace to 855°C, then lowered into the drop cradle, and impacted within a 29-sec period. The air cool-down graph gives an impact skin temperature of 797°C and a sub-surface temperature of 820°C. The high-speed movie camera failed to operate; therefore, no impact velocity could be obtained. The top end of the capsule was deformed with a 0.170-in. bulge in the wall approximately 1 in. from the end in the threaded area. The top cap was deflected 7/32 in. from the perpendicular with the axis of the capsule. A 2-in.-long hairline crack was also found within the impact area. This deformation is shown in Figs. 42 through 49. A dye penetrant check was used to bring out the crack and is shown in Fig. 47. The vacuum leak test was positive and is shown in Fig. 48. A sketch of the impact area is shown in Fig. 49.

Following completion of the testing program, the top end was cut from the capsule and sectioned for inspection. Figure 50 shows the sheared plasma arc weld within the impact area. The capsule wall within the screw thread area was not sufficiently strong to resist the impact force and gave way; this allowed the threads to separate.

Figure 51 is the weld section 180° from the impact area and does not show deformation.

Capsule No. 2 was inverted and free dropped upon the bottom end edge in which the bottom cap was electron-beam welded into the capsule. The capsule was heated to 844°C, lowered into the drop cradle, and impacted

within a 36-sec period. The air cool-down graph gives a skin temperature of 786°C and a sub-surface temperature of 805°C.

The impact caused a 0.060-in. bulge in the capsule wall near the inner edge of the bottom end cap, and the end was deflected 3/16 in. from the perpendicular with the capsule axis. The bottom end deformation is shown in Figs. 52 through 55. A sketch of the deformation is shown in Fig. 56. The crack in the top end of the capsule was sealed with Glyptol, and then the capsule was vacuum leak tested with no leaks detected. A high-speed film (2000 frames/sec) of the bottom end impact showed an impact velocity of 42.6 ± 1.3 ft/sec. A free drop velocity for 29 ft 7 in. is 43.6 ft/sec. The camera speed accuracy is ±3%. The electron-beam-welded end withstood the impact well. Following completion of tests, the end of the capsule was cut off and the bottom end cap was sectioned so that the welds could be viewed in the impact area and 180° from the impact. Figure 57 shows the weld within the impact area. The wall has bulged away from the cap and the capsule shoulder and cap edge has yielded; however, the weld is intact except for a very short crack (0.047 in.) at the root. The weld still has a depth of 0.320 in. and mid-width of 0.063 in. Figure 2 shows the weld 180° from the impact area, which has a weld depth of 0.359 in. and a mid-width of 0.063 in.

The final test for capsule No. 2 was the percussion test; Fig. 58 shows the test equipment. The capsule was heated in the furnace to 825°C and quickly placed upon a 1/16-in.-thick steel plate that covered a 1/4-in.-thick lead sheet, which was lying on a 4-in.-thick reinforced concrete pad. The 1-in.-diam bar, weighing 15.43 lb (7 kg) was dropped 40 in. through a 1-1/2-in.-diam guide tube placed on the middle of the capsule. There was no significant change in dimensions and no leaks detected. Figures 59, 60, and 61 show the capsule post-test condition. The test did vary from the stated procedure listed in Appendix I in that a 1/4-in.-thick lead sheet was used in place of the 1-in.-thick sheet. IAEA Safety Series No. 33 states that lead of a thickness not greater than 25 mm shall cover an area greater than that covered by the capsule. Therefore, the test does meet the requirements.

CONCLUSION

The only tests of the series to cause any significant capsule deformation were the hydrostatic pressure test to 14,505 psig, the 9.0-meter free drop test, and the vibration test. The capsules successfully passed the series of tests with the exception of the free drop test upon the capsule's plasma-arc seal-welded screw-in top cap. The impact forces upon the edge of the capsule, while at an approximated operating temperature, caused the capsule to deform in the threaded area to the point that the threads were no longer engaged, and the capsule shoulder and seal weld sheared. A modified design of this type of top cap would be required before the capsule as presently designed could meet the test requirements for containment. The electron-beam-welded bottom cap design did easily pass all tests and can be used for the top closure also, which would qualify the capsule in all of the tests prescribed by applicable regulations.

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5. L. A. Becker and G. A. Schnieder, *Pressure Test of Two Fuel Capsules*, Naval Ship Research and Development Center, February 1973.

APPENDIX I

Test Procedures and Data Sheets

1. IKP Capsule Preconditioning Heat Treatment Procedure
2. Hydrostatic Pressure Test
3. Immersion Test
4. Vibration Test
5. Heating Test
6. Thermal Shock Test
7. Free Drop Test on Top End
8. Free Drop Test on Bottom End
9. Percussion Test
10. Leak Test Procedure

IKP Capsule Preconditioning Heat Treatment Procedure

Purpose

The purpose of the preconditioning heat treatment of the IKP capsule is to insure that the metallurgical condition of the Hastelloy C-276 test capsules are representative of an actual capsule after being exposed to an operating environment. Leonard[1] reports that grain-boundary precipitates can form in alloy C-276 when it is exposed to temperatures from 1200 to 2000°F. The maximum precipitation occurs at 1600°F with a sharp drop at higher and lower temperatures. The precipitates have been identified as either "P"- or Ni_7Mo_6-type phase. No M_6C precipitate was found in alloy C-276.

The expected shipping and storage temperatures of the IKP capsules are each approximately 1000°F. Operating temperature is expected to be about 1400°F and loss-of-coolant condition temperature is estimated to be 1900°F. All of these temperatures are significantly less than the precipitation solution temperature of 2100°F.

The formation of the "P"-type precipitate is evident in all cases in less than one hour in the case of the temperatures of interest here. The Ni_7Mo_6-type prepcipitate is formed in all cases in less than 30 hr. Specifically at 1600°F the "P"-type phase precipitate forms at about 5.5 min and the Ni_7Mo_6-type phase precipitate at about 55 min.

Test Procedure

Capsule #1 1-3-73
Capsule #2 1-5-73

1. Visually inspect the capsule and photograph.
2. Leak test the capsule.
3. Dimensionally inspect the capsule.
4. Place the capsule in heat treatment furnace at 1600°F for 1 hr.
5. Remove capsule from furnace and allow to air cool to ambient temperature.
6. Leak test the capsule.
7. Dimensionally inspect the capsule.

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[1]R. B. Leonard, *Thermal Stability of "Hastelloy" Alloy C-276*, Report No. 7409, Union Carbide Croporation, Materials Systems Division (now Cabot Corporation), Jan. 3, 1968.

TEST PROCEDURE FOR ISOTOPES KILOWATT CAPSULE

Hydrostatic Pressure Test

Test Conditions

1. The test is to be conducted at ambient temperature conditions.

2. The test capsule shall be a full-sized capsule loaded with inactive $SrTiO_3$ fuel material. The capsule shall be identical in all respects to an actively fueled capsule except for the inactive fuel.

3. The capsule shall be tested in a pressure vessel of sufficient size and capacity to completely contain the capsule with a minimum space of 1 in. on the sides and the top and bottom. No special spacers are required, however, to hold the capsule in any particular orientation and the capsule may rest on the bottom of the pressure vessel.

4. The capsule shall be exposed to an external pressure of 1000 bars (14,505 psi) in the test.

5. The capsule shall be dimensionally inspected and leak tested prior to and at the conclusion of the test. The leak test shall be capable of detecting a leak of 3×10^{-6} cm^3/sec at STP or less.

Hydrostatic Pressure Test (continued)

Test Procedure*

1. Dimensionally inspect capsule.

2. Leak test capsule.

3. Place capsule in test chamber.

4. Pressurize the test chamber to test pressure utilizing the following procedure:

   a. Increase pressure to 1000 psig.

   b. Hold at pressure for 5 min.

   c. Continue increasing pressure in 1000-psig increments, holding the pressure for 5 min at each incremental pressure, until the test pressure of 14,505 psig is reached.

5. Hold at test pressure (14,505 psig) for 1 hr.

6. Bleed pressure off test chamber utilizing the following procedure:

   a. Reduce pressure by 1000 psig.

   b. Hold at this pressure for 5 min.

   c. Continue decreasing pressure in 1000-psig increments, holding the pressure for 5 min at each incremental pressure, until the chamber is at 0 psig.

7. Remove capsule from test chamber.

8. Leak test capsule.

9. Dimensionally inspect capsule and photograph.

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*Items 3 through 7 are to be performed at a Navy Laboratory; all other items are to be conducted by Oak Ridge National Laboratory.

Data Sheet — Hydrostatic Pressure Test* Capsule Identification No. 1

	Date	Initials
1. Photograph capsule	1/4/73	KWH
2. Photograph test equipment *		
3. Dimensionally inspect capsule†	1/4/73	KWH

Record pertinent dimensions:

Diam (include any variation along length) _____

Length _____

Parallelism of top and bottom _____

Perpendicularity _____

} see data sheets 1/4/73 KWH

4. Leak test capsule

Results negative 1/4/73 KWH

5. Using outlined procedure, pressurize the test chamber and capsule, hold at pressure and depressurize

Pressure	Time	Pressure	Time	Pressure	Time
0	0943	12,000	1211	6,000	1435
1,000	0949	13,000	1224	5,000	1441
2,000	1002	14,000	1237	4,000	1447
3,000	1015	14,505	1246	3,000	1453
4,000	1028	14,000	1347	2,000	1459
5,000	1041	13,000	1353	1,000	1506
6,000	1054	12,000	1359	0	1514
7,000	1107	11,000	1405		
8,000	1120	10,000	1411		
9,000	1133	9,000	1417		
10,000	1146	8,000	1423		
11,000	1159	7,000	1429		

Data Sheet — Hydrostatic Pressure Test (continued) Capsule No. 1

	Date	Initials
6. Leak test capsule		
Results No Leak	3-8-73	MJB
7. Dimensionally inspect capsule and compare with results in step 3.*	3-8-73	MJB
Diam (include any variation along length) −0.140		
Length −0.073		
Parallelism of top and bottom +0.007		
Perpendicularity Bottom +0.009		
8. Photograph capsule	3-9-73	MJB

9. Remarks _____

*Item 2 and 5 to be done by a Navy Laboratory; all other items to be performed by Oak Ridge National Laboratory.
†Attach dimensional inspection sheets and sketches as required.

TEST PROCEDURES FOR ISOTOPES KILOWATT CAPSULE

Immersion Test

Test Conditions

1. The test consists of immersing the capsule in water at room temperature for 24 hr.

2. The test capsule shall be a full-sized capsule loaded with inactive $SrTiO_3$ fuel material. The capsule shall be identical in all respects to an actively fueled capsule except for the inactive fuel.

3. The capsule shall be immersed in a water container of sufficient size to completely contain the capsule to a depth of at least 2 ft above the top surface of the capsule.

4. The capsule shall be leak tested prior to and at the conclusion of the test. The leak test shall be capable of detecting a leak of 3×10^{-6} cm^3/sec at STP or less.

Test Procedure

1. Leak test capsule.

2. Place capsule in immersion tank with at least 2 ft of water above the top surface of the capsule at room temperature.

3. Allow the capsule to remain in the immersion tank underwater for 24 hr.

4. Remove capsule from immersion tank and leak test.

Data Sheet — Immersion Test

Capsule Identification No. _____

		Date	Initials
1.	Leak test capsule		
	Results No Leak	3-8-73	MB
2.	Photograph capsule	3-9-73	MB
3.	Time in immersion tank 12:50	3-9-73	MB
4.	Time out of immersion tank 13:00	3-12-73	MB
5.	Leak test capsule		
	Results No Leak	3-12-73	MB
6.	Photograph capsule	3-12-73	MB

TEST PROCEDURE FOR ISOTOPES KILOWATT CAPSULE

Vibration Test

Test Conditions

1. A resonant survey shall be made of the capsule to determine the principal vibration mode of the capsule. The capsule shall be tested at each of these principal modes for a period of 30 min at 1-, 2-, 3-, 4-, and 5-G force loading.

2. The test capsule shall be a full-sized capsule loaded with inactive $SrTiO_3$ fuel material. The capsule shall be identical in all respects to an actively fueled capsule except for the inactive fuel.

3. The vibration testing equipment shall have a 550 force pound shaker table large enough to securely fasten the capsule to it and shall be capable of scanning over a frequency range of 0 to 5000 cycles/sec.

4. The coupling device between the capsule and the shaker table shall consist of a 4-in.-diam pipe flanged on one end to bolt to the shaker table and with a pinned yoke on the other. The pinned yoke will connect to a collar which is fastened, by bolting, securely around the center of the capsule.

5. The capsule shall be freely suspended in a vertical position 10 in. in front of the shaker table. The shaker table shall be mounted perpendicularily to the source capsule.

6. The capsule shall be leak tested prior to and at the conclusion of the test. The leak test method shall be capable of detecting a leak of 3×10^{-6} cm^3/sec at STP or less.

Test Procedure

1. Leak test capsule.

2. Vertically suspend capsule approximately 10 in. from shaker table. Shaker table shall be in the horizontal position. Connect positive coupling device to capsule and shaker table.

3. Scan the frequency range of 0 to 5000 cycles/sec and record each resonance mode observed.

4. Test capsule for 30 min at each observed resonance mode frequency at 1, 2, 3, 4, and 5 G's.

5. Leak test the capsule.

IKP Capsule No. 1
Vibration Test

Date	Beginning Time	Frequency (cycles/sec)	Control (G)	Capsule (G)	End Time
3-29-73		385	0.2	0.32	
		810	0.2	0.85	
		1140	0.2	0.49	
		2550	0.2	0.46	
		3000	0.2	0.42	
3-29-73	3:10	385	1.0	1.8	3:40
3-30-73	9:15	385	0.9	1.0	9:45
	9:45	385	1.7	3.0	10:15
	10:15	385	2.0	4.0	10:45
	10:45	385	2.6	5.0	11:15
	11:15	810	0.5	1.0	11:45
	12:15	810	1.1	2.0	12:45
	12:45	810	2.2	3.0	1:15
	1:15	810	2.6	4.0	1:45
	1:45	810	2.9	5.0	2:15
	2:15	1140	0.6	1.0	2:45
	2:45	1140	0.8	2.0	3:15
	3:15	1140	2.0	3.0	3:45
4-2-73	9:00	1140	2.4	4.0	9:30
	9:30	1140	2.7	5.0	10:00
	10:00	2550	1.0	1.0	10:30
	10:30	2550	1.7	2.0	11:00
	11:00	2550	2.8	3.0	11:30
	12:00	2550	2.5	4.0	12:30
	12:30	2550	3.0	5.0	1:00
	1:00	3000	1.1	1.0	1:30
	1:30	3000	1.7	2.0	2:00
	2:00	3000	4.0	3.0	2:30
	2:30	3000	4.6	4.0	3:00
	3:00	3000	5.2	5.0	3:30

Data Sheet — Vibration Test

Capsule Identification No. 1

	Date	Initials
1. Leak test capsule		
Results No Leak	3-12-73	JCB
2. Photograph capsule	3-12-73	JCB
3. Photograph test equipment	4-2-73	JCB
4. Resonant frequencies	3-29-73	JCB

385 810 1140 2550

3000

5. Describe test results or any unusual circumstances	4-2-73	JCB

1 G Nothing happened at any loading.

2 G

3 G

4 G

5 G

6. Photograph capsule	4-3-73	JCB
7. Leak test capsule		
Results No Leak		JCB

TEST PROCEDURES FOR ISOTOPES KILOWATT CAPSULE

Heating Test

Test Conditions

1. The test consists of heating the capsule, in air, to a temperature of 1475°F (800°C), remaining at that temperature for 30 min, and cooling to ambient temperature in air.

2. The test capsule shall be a full-sized capsule loaded with inactive $SrTiO_3$ fuel material. The capsule shall be identical in all respects to an actively fueled capsule except for the inactive fuel.

3. The capsule shall be heated in a furnace of sufficient size and capacity to evenly heat the entire capsule and allow air circulation around the capsule.

4. The capsule shall be leak tested prior to and at the conclusion of the test. The leak test shall be capable of detecting a leak of 3×10^{-6} cm^3/sec at STP or less.

Test Procedure

1. Leak test the capsule.

2. Dimensionally inspect the capsule.

3. Place capsule in furnace and heat to 1475°F (800°C).

4. Hold capsule at temperature for 30 min.

5. Turn furnace off and allow capsule and furnace to cool to ambient conditions.

6. Leak test capsule.

7. Dimensionally inspect the capsule.

Data Sheet — Heating Test

Capsule Identification No. 2

		Date	Initials
1.	Leak test capsule		
	Results No Leak	1-8-73	[illegible]
2.	Dimensionally inspect the capsule*	[illegible]	[illegible]
3.	Photograph capsule	[illegible]	[illegible]
4.	Heat capsule to 800°C	[illegible]	[illegible]
	Time in furnace 1333		
	Time reached temperature 1552		
5.	Hold capsule at temperature 30 min	[illegible]	[illegible]
	Time began [illegible] Time ended [illegible]		
6.	Time furnace off [illegible]	1-8-73	[illegible]
7.	Leak test capsule		
	Results Good	1-9-73	[illegible]
8.	Dimensionally inspect the capsule*	1-9-73	[illegible]
9.	Photograph capsule	1-9-73	[illegible]
10.	Remarks		

*Attach dimensional inspection sheets and sketches as required.

TEST PROCEDURES FOR ISOTOPES KILOWATT CAPSULE

Thermal Shock Test

Test Conditions

1. The test shall consist of heating the capsule to 1475°F (800°C) and immediately upon removal of the capsule from the furnace plunging it into a water-ethylene glycol solution at 32°F (0°C).

2. The test capsule shall be a full-sized capsule loaded with inactive $SrTiO_3$ fuel material. The capsule shall be identical in all respects to an actively fueled capsule except for the inactive fuel.

3. The water tank shall be of sufficient size that the temperature rise of the solution will be limited to 9°F (5°C) or the solution shall be precooled sufficiently below 32°F (0°C) to limit the temperature to 41°F (5°C) at the end of the test. Solution in the tank shall be circulated.

4. The capsule shall be heated in a furnace of sufficient size and capacity to evenly heat the entire capsule.

5. The capsule shall be leak tested prior to and at the conclusion of the test. The leak test shall be capable of detecting a leak of 3×10^{-6} cm^3/sec at STP or less.

Test Procedure

1. Leak test the capsule.

2. Dimensionally inspect the capsule.

3. Heat capsule in furnace to 1475°F (800°C).

4. Prepare cooling bath to required temperature (this will be done concurrently with step 3 above).

5. Remove capsule from furnace and immediately plunge into cooling bath.

6. Allow capsule to remain in cooling bath for 1 hr. Monitor temperature of bath to assure that temperature limits have not been exceeded.

7. Remove capsule from cooling bath and leak test.

8. Dimensionally inspect the capsule.

Data Sheet — Thermal Shock Test Capsule Identification No. 2

	Date	Initials
1. Photograph capsule	1-9-73	MCB
2. Dimensionally inspect the capsule*	1-9-73	MCB
3. Leak test capsule		
Results No Leak	1-9-73	MCB
4. Heat capsule to 800°C	1-10-73	MCB
Time in furnace 0800		
Time reached temperature 1000		
5. Place capsule in cooling bath	1-10-73	MCB
Time in bath 1100 Temp of bath ½ °C		
Time out of bath 1200 Temp of bath 2 °C		
6. Describe test results or any unusual circumstances	1-10-73	MCB
4°C at ~¼ inch above capsule ~5 min. following insertion in bath. Some ice remained in bath during Test.		
7. Dimensionally inspect the capsule*	1-15-73	MCB
8. Leak test capsule		
Results No Leak	1-10-73	MCB
9. Photograph capsule	1-10-73	MCB

*Attach dimensional inspection sheets and sketches as required.

TEST PROCEDURES FOR ISOTOPES KILOWATT CAPSULE

Free Drop Test

Test Conditions

1. The test consists of dropping the capsule through a distance of 30 ft onto a flat, essentially unyielding, horizontal surface in such a way as to suffer maximum damage. The capsule will be heated to 1475°F (800°C) for the test.*

2. The capsule shall be dropped so that it hits on an edge of the top weld at an angle such that a line drawn through the center of mass of the capsule and the point of impact is perpendicular to the impact surface.

3. To assure that the capsule hits at the proper angle a guide bracket may be used to guide the capsule. The guide bracket system shall be tested using a piece of iron or steel of equal weight to the capsule. Any reduction of impact velocity shall be corrected for by raising the height of the capsule above 30 ft.

4. The capsule shall be heated in a clam shell type tube furnace of sufficient size and capacity to evenly heat the entire capsule.

5. The test capsule shall be a full-sized capsule loaded with inactive $SrTiO_3$ fuel material. The capsule shall be identical in all respects to an actively fueled capsule except for the inactive fuel.

6. The impact area shall be a flat, essentially unyielding surface.

7. The capsule shall be leak tested prior to and at the conclusion of the test. The leak test shall be capable of detecting a leak of 3×10^{-6} cm^3/sec at STP or less.

8. High-speed movies shall be taken of the drop test to establish speed and verify the angle of impact.

---

*The capsule shall be heated to some higher temperature to compensate for cooling of the capsule between removal from the furnace and performing the test. This temperature is to be determined by experiment with a piece of iron or steel of equal weight to the capsule.

Free Drop Test (continued)

Test Procedure

1. Leak test capsule and photograph.

2. Dimensionally inspect capsule (particular emphasis shall be placed on the area of direct impact).

3. Heat capsule to 855 °C.*

4. Remove capsule from furnace (furnace and controls shall be located on top of 30-ft drop tower) and immediately place in drop test orientation guide and drop capsule from 30 ft onto drop pad. NOTE: Orientation guide will hold capsule in desired orientation for impact.

5. High-speed movies are to be taken of the drop test and impact.

6. Dimensionally inspect the capsule (make drawing of capsule impact areas and note changes in dimensions).

7. Leak test the capsule and photograph.

Data Sheet — Free Drop Test — Top End Capsule Identification No. 2

		Date	Initials
1.	Leak test the capsule		
	Results OK	1-10-73	[illegible]
2.	Dimensionally inspect capsule*	1-15-73	[illegible]
3.	Photograph capsule	1-10-73	[illegible]
4.	Heat capsule to 856 °C†	1-18-73	[illegible]
	Time in furnace 9:00 AM Capsule temp at release - 747°C		
	Time reached temperature 11:30 AM		
5.	Place capsule in drop test orientation guide and drop capsule	1-18-73	[illegible]
6.	Take high-speed movies of drop test Failed	1-18-73	[illegible]
7.	Dimensionally inspect capsule and make sketch of impacted area showing changes in dimensions*	1-19-73	[illegible]
8.	Leak Test Capsule		
	Results 2" crack - leak	1-19-73	[illegible]
9.	Photograph capsule	1-19-73	[illegible]
10.	Remarks 2 inch crack in weld area on Top		

*Attach dimensional inspection sheets and sketches as required.
†See note on temperature at bottom of Test Conditions. Insert actual temperature to which capsule was heated.

Data Sheet — Free Drop Test - Bottom End Capsule Identification No. 2

		Date	Initials
1.	Leak test the capsule		
	Results Leak - Gross - 2 inch Crack	1-19-73	MB
2.	Dimensionally inspect capsule*	1-19-73	MB
3.	Photograph capsule	1-19-73	MB
4.	Heat capsule to 844 °C†	1-22-73	MB
	Time in furnace 10:50 AM		
	Time reached temperature 2:18 pm	Drop Temp. = 740°C 6 in. above end	
5.	Place capsule in drop test orientation guide and drop capsule	1-22-73	MB
6.	Take high-speed movies of drop test	1-22-73	MB
7.	Dimensionally inspect capsule and make sketch of impacted area showing changes in dimensions*	1-23-73	MB
8.	Leak Test Capsule		
	Results Good	1-25-73	MB
9.	Photograph capsule	1-24-73	MB

10. Remarks Glyptol coated crack on Top end prior to Leak Testing.

*Attach dimensional inspection sheets and sketches as required.
†See note on temperature at bottom of Test Conditions. Insert actual temperature to which capsule was heated.

TEST PROCEDURE FOR ISOTOPES KILOWATT CAPSULE

Percussion Test

Test Conditions

1. The test is to be conducted with the capsule at 1475°F (800°C).*

2. The test capsule shall be a full-sized capsule loaded with inactive $SrTiO_3$ fuel material. The capsule shall be identical in all respects to an actively fueled capsule except for the inactive fuel.

3. The capsule shall be heated in a furnace of sufficient size and capacity to evenly heat the entire capsule.

4. The capsule shall be placed on a 1-in.-thick sheet of lead of hardness 3.5 to 4.5 Vickers which shall be supported by a reinforced concrete floor at least 4 in. thick. The lead shall be covered with 1/16-in.-thick sheet of stainless steel to prevent its melting. No melting of lead is allowed. Therefore, a time limit of 15 sec is imposed between placing the capsule and dropping the impact rod.

5. The rod, which is to be dropped on the capsule, shall be 1.0 in. in diameter and of sufficient length to weigh 15.43 lb (7 kg). The end of the rod which is to impact the capsule shall be flat with edges rounded off to a radius of not less than 3 mm.

6. The rod shall be dropped 40 in. onto the center of the capsule that is on its side. The rod shall be guided by a mechanism to assure that it is held upright and perpendicular to the capsule surface to be impacted.†

7. The capsule shall be dimensionally inspected and leak tested prior to and at the conclusion of the test. The leak test shall be capable of detecting a leak of 3×10^{-6} cm^3/sec at STP or less.

---

*The capsule shall be heated to some higher temperature to compensate for cooling of the capsule between removal from the furnace and performing the test. This temperature is to be determined by experiment with a piece of iron or steel of equal weight to the capsule.

†Actual height of drop is to be determined by experiment to compensate for frictional draft introduced by the guide mechanism.

Percussion Test (continued)

Test Procedure

1. Dimensionally inspect capsule.

2. Leak test capsule.

3. Place capsule in furnace and heat to 825 °C.*

4. Remove capsule from furnace and place on lead sheet covered with 1/16-in.-thick sheet of stainless steel.

5. Drop impact rod onto the capsule in the approximate center of the length of the capsule. Rod shall be dropped to impact perpendicularly with the capsule. Time lapse between positioning the capsule and impacting with the impact rod shall not be greater than 15 sec to prevent excessive cooling of the capsule or melting of lead.

6. Allow the capsule to cool to ambient temperature.

7. Leak test the capsule.

8. Dimensionally inspect the capsule and photograph.

---

*See note on temperature at bottom of Test Conditions. Insert actual temperature to which capsule was heated.

Data Sheet — Percussion Test

Capsule Identification No. 2

	Date	Initials
1. Photograph capsule	1-24-73	MCB
2. Photograph test equipment	1-25-73	MCB
3. Dimensionally inspect capsule in area to be impacted*	1-23-73	MCB

Results See dimensional inspection sheet

4. Leak test capsule

Results No Leak 1-25-73 MCB

5. Heat capsule to 825 °C† 1-26-73 MCB

Time capsule in furnace 0900 AM

Time capsule reached temperature 1030 AM

6. Remarks on test‡ 1-26-73 MCB

Drop #1 at capsule Middle 40 inch height in vented Tube guide. 10 sec after removal from furnace. No change

Drop #2 on concrete pad ~6 inches from end - 40 inch height

7. Photograph capsule 2-2-73 MCB

8. Leak test capsule

Results No Leak 2-6-73 MCB

9. Dimensionally inspect capsule in impact area* 1-31-73 MCB

Results No detectable change

*Attach dimensional inspection sheets as required.
†See note on temperature at bottom of Test Conditions; insert actual temperature to which capsule was heated.
‡Remarks shall include actual height of drop and time from positioning capsule to completion of test in addition to any other pertinent remarks.

Leak Test

Isotope Kilowatt Program Fuel Capsule

The leak test to be used for the IFP capsule tests is the ORNL vacuum leak test. Experimental work and practical experience in using this test are found in the following references:

C. R. King, *Vacuum Leak Testing of Radioactive Source Capsules*, ORNL-3664, Oak Ridge National Laboratory (January 1965)

K. W. Haff, R. G. Niemeyer, and R. A. Robinson, *Radioisotope Source Safety Testing*, ORNL-4092, Oak Ridge National Laboratory (May 1967)

R. G. Niemeyer, *Leak Testing Encapsulated Radioactive Sources*, ORNL-4529, Oak Ridge National Laboratory (July 1972)

The vacuum leak test procedure and a brief discussion of the test are extracted from ORNL-4529 as follows:

Vacuum Leak Test Procedure

1. Evacuate the leak test chamber for 1 min or longer to lower the dissolved air content of the leak test fluid (reagent-grade ethylene glycol or isopropyl alcohol).

2. Place the source capsule in the leak test chamber, making certain that it is completely submerged to a depth of 2 in. below the fluid level.

3. Evacuate the leak test chamber slowly to 2.5 psia, while observing for the indication of leaks by bubbles rising from the source capsule surface. If no leaks are observed over a period of 5 min, the source capsule passes this leak test.

Discussion of Bubble Leak Tests

The vacuum leak test, the hot-water bubble test, and a part of the vacuum leach test fall into a general class of tests commonly referred to as bubble leak tests. The source capsule is immersed in a liquid to a depth of about 2 in., and a pressure differential is established between the inside of the capsule and the surrounding such that gas can pass from the capsule interior through a leak hole in the capsule and be detected by observing the resulting stream of bubbles emanating from the point of leakage. The pressure differential is obtained by prepressurization of the capsule, by reducing the pressure above the liquid, or by placing the capsuly into a liquid which is at a higher temperature. There must be sufficient free void volume within the source capsule to support a stream of bubbles for this type of test

Leak Test (continued)

to be valid. Bubble leak tests have been used successfully on source capsules having free volumes as small as 0.1 cm^3; however, this is considered to be the minimum volume at which it should be used. At ORNL, an arbitrary minimum void volume of 0.25 cm^3 is used for bubble leak testing.

When prepressurization is used, the pressure and time must be selected so that sufficient gas will leak into the source to give the desired sensitivity. Additional time must be allowed under pressure to account for loss of internal capsule pressure during the time interval between pressurization and testing. If helium is used for prepressurization, the full advantages of helium will not be obtained unless the air is first removed from the capsule by evacuation. The use of flammable gases or liquids in hot cells is not normally advisable due to fire and explosion hazards. When the pressure differential is obtained by a vaccum over the liquid, some of the liquid can be drawn inside the capsule through a leak hole when the vacuum is released at the end of the test. Unless this liquid can be removed, serious difficulties could be encountered if attempts were made to repair the leak. If the capsule is sealed with residual liquid inside, excessive pressures may be generated later inside the capsule by radiolysis of the liquid, or by abnormally high environmental temperatures which will cause liquid expansion or vaporization.

To some extent, both reliability and sensitivity of these tests depend on the operator performing the test. Careful observation is required throughout a test to be sure that leaks will not be missed. Small bubbles or a low bubbling rate can make very small leaks difficult to see, and very large leaks in which the gas escapes in one or two bubbles might be missed. Corrosion or air pockets on the external surfaces of the capsule can give false indications of a leak. Good lighting is important and moderate magnification (2 to 4X) is helpful. The area where leaks are most likely to occur (seal areas) should be clearly visible to the operator. The liquid used should be outgassed so that the extraneous bubbling will not interfere with the test. When the pressure differential is obtained by means of vacuum, the vacuum should be applied slowly, and the operator should be observing for leaks from the moment the vacuum is applied to avoid missing large leaks.

When one of the bubble leak tests is used, a stream of bubbles emanating from a source capsule indicates that the outer source capsule is leaking. The inner source capsule may or may not be leaking. In order to be reasonably certain that the inner capsule does not leak, it must be leak tested before it is loaded into the outer source capsule, or the assembled source must be leak tested using a method which will detect leaks in both inner and outer source capsules. The bubble leak tests will indicate both the presence and the location of all leaks in the outer source capsule provided the free void volume is large enough and the pressure drop across each leak is sufficient to cause bubbling from each leak.

Leak Test (continued)

For bubble leak tests where the leak flow is into a liquid under vacuum, such as the vacuum leak test and vacuum leach test, the pressure differential (ΔP) necessary to initiate bubbling is approximately $4T/D$, where T is the surface tension of the liquid and D is the diameter of the leak hole. The development of this equation and experimental data demonstrating its validity are given in ORNL-3664 (reference above). For leak tests, such as the hot-water bubble test, where the flow is into a liquid at atmospheric pressure, the relationship $\Delta P = 4T/D$ is invalid.

Discussion of Vacuum Leak Test

The source is immersed in isopropyl alcohol or ethylene glycol to a depth of about 2 in. below the surface. The pressure above the liquid is then slowly reduced to 2.5 psia. A leak is indicated by a stream of bubbles rising through the liquid from a point on the source capsule.

The sensitivity of this test has been determined by preparing a number of calibrated leaks, measuring the hole sizes microscopically, and measuring the leak rates. Under the test conditions described, leaks as small as $\sim 4 \times 10^{-6}$ atm cm^3/sec (for 1-μm diam) can be readily detected, and smaller leaks have been detected by pressurizing the capsules with air immediately before the leak test. The sensitivity of the vacuum leak test can be brought almost to the level of the helium and ^{85}Kr leak-detection methods (10^{-8} to 10^{-10} atm cm^3/sec) by the use of prepressurization techniques.

The discussion of bubble testing should be taken into consideration when the vacuum leak test is used.

APPENDIX II

Dimensional Inspection Reports

1. Data Sheets for Dimensional Measurements on Capsule No. 1
2. Data Sheets for Dimensional Measurements on Capsule No. 2

Dimensional Measurements

Isotope Kilowatt Program Fuel Capsule

Dimensional measurements for the IKP fuel capsule are taken in accordance with the following format:

Each capsule shall be marked to define top, bottom, middle, 1 in. from either end, and radial positions at 0°, 45°, 90°, 135°, 180°, 225°, 270°, and 315°.

The design dimension and tolerance for each dimension to be recorded shall be shown adjacent to the recording position on the data sheet to provide greater ease of comparison.

The following dimensional measurements shall be made:

Radial — At middle of capsule and 1 in. from either end at the following positions:

Position 1	0° — 180°
Position 2	45° — 225°
Position 3	90° — 270°
Position 4	135° — 315°

Length — Measured at center of ends of capsule.

Total-indicated-runout — The axial total-indicated-runout (TIR) shall be measured at positions of 0°, 90°, 180°, and 270° from end to end.

Parallelism — The degree of parallelism of the top and bottom shall be recorded.

Perpendicularity — The degree of perpencidularity of the axis of the capsule with the ends shall be recorded.

Dimensional Measurements Data

Isotope Kilowatt Program Fuel Capsule

Sheet No. 1-1 Capsule Identification No. 1

Test Title Initial Heat Treatment

Pre-test X Post-test _____

RADIAL

Position	Actual (in.) 1 in. from Top	Middle	1 in. from Bottom	Design (in.)
1	4.1005"	4.1010"	4.0982"	4.100 ± 0.002
2	4.1009"	4.1010"	4.0982"	
3	4.1007"	4.1010"	4.0998"	
4	4.1006"	4.1010"	4.0985"	

LENGTH

Actual 40.413 in. Design 40.~~260~~ 400 ± 0.005 in.

TOTAL-INDICATED-RUNOUT

Position	Actual (in.)	Design (in.)
0°	.0027	±0.003
90°	.0025	
180°	.0030	
270°	.0010	

PARALLELISM

Actual _____ in. Design ±0.005 in.

PERPENDICULARITY

Actual Top .007 in. Design ±0.005 in.
Bot. .004

After Annealed

Dimensional Measurements Data

Isotope Kilowatt Program Fuel Capsule

Sheet No. 1-2 Capsule Identification No. 1

Test Title Post Heat Treat Pre Hydrostatic Pressure Test

Pre-test _____ Post-test _____

RADIAL

Position	Actual (in.) 1 in. from Top	Middle	1 in. from Bottom	Design (in.)
1	4.099"	4.100"	4.0976"	4.100 ± 0.002
2	4.0998"	4.1003"	4.0986"	
3	4.0998"	4.1003"	4.0988"	
4	4.0996"	4.1002"	4.098"	

LENGTH

Actual 40.402 in. Design 40.~~200~~ 400 ± 0.005 in.

TOTAL-INDICATED-RUNOUT

Position	Actual (in.)	Design (in.)
0°	.003"	±0.003
90°	.0025"	
180°	.003"	
270°	.0023"	

PARALLELISM

Actual .005 in. Design ±0.005 in.

PERPENDICULARITY

Actual .003 Bottom in. Design ±0.005 in.

Top .007

TABLE 1

DIMENSIONAL CHECK OF CAPSULE 1

Radial (Design 4.100 ± 0.002)					
Location	Position	Pre-Heat Treatment	Post Heat Treatment	Pre Test at NSRDC	Post Test at NSRDC
1 in. from top	1	4.1005	4.099	4.101	4.086
	2	4.1009	4.0998		4.095
	3	4.1007	4.0998	4.101	4.080
	4	4.1006	4.0996		4.074
Middle	1	4.1010	4.100	4.099	
	2	4.1010	4.1003		
	3	4.1010	4.1002	4.102	
	4	4.1010	4.1002		
1 in. from bottom	1	4.0982	4.0976	4.100	4.100
	2	4.0982	4.0986		4.102
	3	4.0998	4.0988	4.0985	4.101
	4	4.0995	4.098		4.100
Length (Design 40.280 ± 0.005)					
		40.413	40.402		
Total Indicated Runout (Design ± 0.003)					
	0	.0027	.003		
	90	.0025	.0025		
	180	.0030	.003		
	270	.0010	.0023		
Parallelism (Design ± 0.005)			.005		
Perpendicularism (Design ± 0.005)		.007	.007		

Q. A. LEVEL NO. IV

Dimensional Measurements Data

Isotope Kilowatt Program Fuel Capsule

Sheet No. 1-3 Capsule Identification No. I

Test Title Post Hydrostatic Test
Pre Imersion Test

Pre-test _____ Post-test _____

RADIAL

Position	Actual (in.) 1 in. from Top	Middle	1 in. from Bottom	Design (in.)
1	4.100	4.110	4.078	4.100 ± 0.002
2	4.105	4.050	4.085	
3	4.110	3.960	4.087	
4	4.102	4.000	4.080	

LENGTH

Actual 40.329 in. Design 40.~~200~~ 400 ± 0.005 in.

TOTAL-INDICATED-RUNOUT

Position	Actual (in.)	Design (in.)
0°	.095	±0.003
90°	.026	
180°	.005	
270°	.010	

PARALLELISM

Actual .012 in. Design ±0.005 in.

PERPENDICULARITY

Actual To Bottom .007 .012 in. Design ±0.005 in.

Dimensional Measurements Data

Isotope Kilowatt Program Fuel Capsule

Sheet No. 1-4 Capsule Identification No. I

Test Title Post Immersion Test ~~Pre Vibration Test~~

Pre-test _____ Post-test _____

RADIAL

Position	Actual (in.) 1 in. from Top	Middle	1 in. from Bottom	Design (in.)
1	4.100	4.109	4.081	4.100 ± 0.002
2	4.104	4.048	4.087	
3	4.109	3.959	4.085	
4	4.102	4.013	4.079	

LENGTH

Actual 40.329 in. Design 40.~~200~~ .400 ± 0.005 in.

TOTAL-INDICATED-RUNOUT

Position	Actual (in.)	Design (in.)
0°	.083	±0.003
90°	.034	
180°	.029	
270°	.023	

PARALLELISM

Actual .012 in. Design ±0.005 in.

PERPENDICULARITY

Actual Top .007 Bottom .013 in. Design ±0.005 in.

Dimensional Measurements Data

Isotope Kilowatt Program Fuel Capsule

Sheet No. 1-5 Capsule Identification No. I

Test Title Post Vibration Test

Pre-test _____ Post-test _____

RADIAL

Position	Actual (in.) 1 in. from Top	Middle	1 in. from Bottom	Design (in.)
1	4.101	4.107	4.095	4.100 ± 0.002
2	4.106	4.043	4.090	
3	4.101	3.962	4.080	
4	4.101	4.049	4.084	

LENGTH

Actual 40.323 in. Design 40.~~200~~ .400 ± 0.005 in.

TOTAL-INDICATED-RUNOUT

Position	Actual (in.)	Design (in.)
0°	.053	±0.003
90°	.140	
180°	.086	
270°	.117	

PARALLELISM

Actual .010 in. Design ±0.005 in.

PERPENDICULARITY

Actual Top .007 Bottom .011 in. Design ±0.005 in.

Dimensional Measurements Data

Isotope Kilowatt Program Fuel Capsule

Sheet No. 2-1 Capsule Identification No. 2

Test Title Initial Heat Treatment

Pre-test X Post-test _____

RADIAL

Position	Actual (in.) 1 in. from Top	Middle	1 in. from Bottom	Design (in.)
1	4.1004"	4.101"	4.1015	4.100 ± 0.002
2	4.1009"	4.101"	4.1015	
3	4.0997"	4.101"	4.1002	
4	4.0996"	4.1009"	4.1007	

LENGTH

Actual 40.420 in. Design 40.~~280~~ 400 ± 0.005 in.

TOTAL-INDICATED-RUNOUT

Position	Actual (in.)	Design (in.)
0°	.002"	±0.003
90°	.002"	
180°	.002"	
270°	.0023"	

PARALLELISM

Actual .010 in. Design ±0.005 in.

PERPENDICULARITY

Actual Top .001" Bot. .012" in. Design ±0.005 in.

JAN 8 1973

Dimensional Measurements Data

Isotope Kilowatt Program Fuel Capsule

Sheet No. 2-2 Post Heat Treat Capsule Identification No. 2

Test Title Pre Heating Test

Pre-test X Post-test ____

RADIAL

Position	Actual (in.) 1 in. from Top	Middle	1 in. from Bottom	Design (in.)
1	4.0989"	4.1001"	4.1013"	4.100 ± 0.002
2	4.0994	4.0999"	4.1013"	
3	4.0987	4.1000"	4.1001"	
4	4.0984	4.1000"	4.0999"	

LENGTH

Actual 40.405 in. Design 40.~~300~~ .400 ± 0.005 in.

TOTAL-INDICATED-RUNOUT

Position	Actual (in.)	Design (in.)
0°	.002"	±0.003
90°	.0015"	
180°	.003"	
270°	.002"	

PARALLELISM

Actual .011" in. Design ±0.005 in.

PERPENDICULARITY

Actual Top .002" in. Design ±0.005 in.
Bot. .015"

1-9-73

Dimensional Measurements Data

Isotope Kilowatt Program Fuel Capsule

Sheet No. 2-3 Capsule Identification No. 2

Test Title Post Heating Test Pre Thermal Shock Test

Pre-test _____ Post-test _____

RADIAL

Position	Actual (in.) 1 in. from Top	Middle	1 in. from Bottom	Design (in.)
1	4.099"	4.0996"	4.1009"	4.100 ± 0.002
2	4.0991"	4.0995"	4.1001"	
3	4.0981"	4.0995"	4.0993"	
4	4.0986"	4.0997"	4.0993"	

LENGTH

Actual 40.408" in. Design 40.~~200~~ 400 ± 0.005 in.

TOTAL-INDICATED-RUNOUT

Position	Actual (in.)	Design (in.)
0°	.002"	±0.003
90°	.003"	
180°	.0025"	
270°	.003"	

PARALLELISM

Actual .0115" in. Design ±0.005 in.

PERPENDICULARITY

Actual Top .002" in. Design ±0.005 in.
Bott .014"

1-15-73

Dimensional Measurements Data

Isotope Kilowatt Program Fuel Capsule

Sheet No. 2-4 Capsule Identification No. 2

Test Title Post Thermal Shock Test Pre 30 ft Drop Test

Pre-test _____ Post-test _____

RADIAL

Position	Actual (in.) 1 in. from Top	Middle	1 in. from Bottom	Design (in.)
1	4.1157"	4.0982"	4.105"	4.100 ± 0.002
2	4.016"	4.102"	4.1077"	
3	4.116"	4.106"	4.107"	
4	4.1158"	4.1029"	4.1065"	

LENGTH

Actual 40.426 in. Design 40.~~280~~ 400 ± 0.005 in.

TOTAL-INDICATED-RUNOUT

Position	Actual (in.)	Design (in.)
0°	.010"	±0.003
90°	.005"	
180°	.011"	
270°	.009"	

PARALLELISM

Actual .017 in. Design ±0.005 in.

PERPENDICULARITY

Actual Top .002 in. Design ±0.005 in.
Bot .017

1-19-73

Dimensional Measurements Data

Isotope Kilowatt Program Fuel Capsule

Sheet No. 2-5 Capsule Identification No. 2

Test Title Post 30 ft Drop Test - Top End
Pre 30 ft Drop Test - Bottom End

Pre-test _____ Post-test _____

RADIAL

Position		Actual (in.) 1 in. from Top	Middle	1 in. from Bottom	Design (in.)
	0°	4.229			
1	22½°	4.198	4.097	4.105	4.100 ± 0.002
	45°	4.195			
2	67°	4.196	4.099	4.106	
	90°	4.205			
3	112°	4.206	4.105	4.105	
	135°	4.210			
4	157°	4.215	4.102	4.106	

LENGTH

Actual 40.3305 in. Design 40.~~280~~ 400 ± 0.005 in.

TOTAL-INDICATED-RUNOUT

Position	Actual (in.)	Design (in.)
0°	.030"	±0.003
90°	.090"	
180°	.150"	
270°	.025"	

PARALLELISM

Actual .213 in. Design ±0.005 in.

PERPENDICULARITY

Actual Top .213 in. Design ±0.005 in.
Bot. .012

Dimensional Measurements Data

Isotope Kilowatt Program Fuel Capsule

Sheet No. 2-6 - Capsule Identification No. 2

Test Title Post 30ft Drop Test - Bottom End
Pre Precussion Test

Pre-test _____ Post-test _____

RADIAL

Position	Actual (in.) 1 in. from Top	Middle	1 in. from Bottom		Design (in.)
1	4.224	4.097	0°	4.155	4.100 ± 0.002
			22½°	4.151	
2	4.195	4.098	45°	4.151	
			67°	4.152	
3	4.204	4.104	90°	4.153	
			112°	4.159	
4	4.209	4.103	135°	4.158	
			157°	4.158	

LENGTH

Actual 40.330 in. Design 40.~~280~~ 400 ± 0.005 in.

TOTAL-INDICATED-RUNOUT

Position	Actual (in.)	Design (in.)
0°	.065	±0.003
90°	.117	
180°	.125	
270°	.060	

PARALLELISM

Actual 13/32 in. Design ±0.005 in.

PERPENDICULARITY

Actual Top 7/32 in. Design ±0.005 in.
Bot. 3/16

1-31-73

Dimensional Measurements Data

Isotope Kilowatt Program Fuel Capsule

Sheet No. 2-7- Capsule Identification No. 2

Test Title Post Percussion Test

Pre-test _____ Post-test ✓

RADIAL

Position	Actual (in.) 1 in. from Top	Middle	1 in. from Bottom	Design (in.)
1	4.187	4.105	4.155	4.100 ± 0.002
2	4.160	4.106	4.153	
3	4.195	4.095	4.158	
4	4.180	4.106	4.152	

LENGTH

Actual 40.359 in. Design 40.~~260~~ 400 ± 0.005 in.

TOTAL-INDICATED-RUNOUT

Position	Actual (in.)	Design (in.)
0°	0	±0.003
90°	.135	
180°	.165	
270°	.040	

PARALLELISM

Actual .475 in. Design ±0.005 in.

PERPENDICULARITY

Actual .210 Top / .160 Bottom in. Design ±0.005 in.

APPENDIX III

Figures of IKP Capsule

Fig. 1. Isotope Kilowatt Program Fuel Capsule. (ORNL Dwg 70-1150R)

Fig. 2. IKP Capsule and Inert $SrTiO_3$ Pellets Prior to Assembly. (ORNL Photo 3247-72)

Fig. 3. Electron-Beam Weld of Bottom Cap on Capsule No. 2, 180° From Impact Area. (ORNL Photo 0562-73)

Fig. 4. Plasma Arc Weld of Test Top Cap, Right Section. (ORNL Photo 0053-73)

Fig. 5. Plasma Arc Weld of Test Top Cap, Left Section. (ORNL Photo 0058-73)

Fig. 6. Plasma Arc Weld of Top Cap on Capsule No. 2, Right Section. (ORNL Photo 0421-73)

Fig. 7. Side View of Completed IKP Capsule No. 1. (ORNL Photo 0021-73)

Fig. 8. Bottom View of Completed IKP Capsule No. 1. (ORNL Photo 0014-73)

Fig. 9. Top View of Completed IKP Capsule No. 1. (ORNL Photo 0013-73)

Fig. 10. Side View of Completed IKP Capsule No. 2. (ORNL Photo 0024-73)

Fig. 11. Bottom View of Completed IKP Capsule No. 2. (ORNL Photo 0017-73)

Fig. 12. Top View of Completed IKP Capsule No. 2. (ORNL Photo 0016-73)

Fig. 13. Vaccum Leak Testing Equipment. (ORNL Photo 0050-73)

Fig. 14. Closeup of a Negative Vacuum Leak Test. (ORNL Photo 0049-73)

Fig. 15. Side View of Capsule No. 1 After Heat Treatment Test. (ORNL Photo 0043-73)

Fig. 16. Bottom End of Capsule No. 1 After Heat Treatment Test. (ORNL Photo 0048-73)

Fig. 17. Top End of Capsule No. 1 After Heat Treatment Test. (ORNL Photo 0047-73)

Fig. 18. Side View of Capsule No. 2 After Heat Treatment Test. (ORNL Photo 0059-73)

Fig. 19. Bottom End of Capsule No. 2 After Heat Treatment Test. (ORNL Photo 0062-73)

Fig. 20. Top End of Capsule No. 2 After Heat Treatment Test. (ORNL Photo 0064-73)

Fig. 21. Side View of Capsule No. 1 After Hydrostatic Pressure Test. (ORNL Photo 0565-73)

Fig. 22. Bottom End of Capsule No. 1 After Hydrostatic Pressure Test. (ORNL Photo 0563-73)

Fig. 23. Top End of Capsule No. 1 After Hydrostatic Pressure Test. (ORNL Photo 0556-73)

Fig. 24. Side View of Top End of Capsule No. 1 After Hydrostatic Pressure Test. (ORNL Photo 0558-73)

Fig. 25. Side View of Middle Section of Capsule No. 1 After Hydrostatic Pressure Test. (ORNL Photo 0561-73)

Fig. 26. Side View of Bottom End of Capsule No. 1 After Hydrostatic Pressure Test. (ORNL Photo 0566-73)

Fig. 27. Side View of Capsule No. 1 After Immersion Test. (ORNL Photo 0564-73)

Fig. 28. Bottom End of Capsule No. 1 After Immersion Test. (ORNL Photo 0557-73)

Fig. 29. Top End of Capsule No. 1 After Immersion Test. (ORNL Photo 0567-73)

Fig. 30. Vibration Testing Equipment. (ORNL Photo 0758-73)

Fig. 31. Vibration Testing Equipment. (ORNL Photo 0762-73)

Fig. 32. Side View of Capsule No. 1 After Vibration Test. (ORNL Photo 0759-73)

Fig. 33. Bottom End of Capsule No. 1 After Vibration Test. (ORNL Photo 0761-73)

Fig. 34. Top End of Capsule No. 1 After Vibration Test. (ORNL Photo 0760-73)

Fig. 35. Air Cool-Down Temperature for Steel Test Piece.

Fig. 36. Side View of Capsule No. 2 After Heat Test. (ORNL Photo 0098-73)

Fig. 37. Bottom End of Capsule No. 2 After Heat Test. (ORNL Photo 0102-73)

Fig. 38. Top End of Capsule No. 2 After Heat Test. (ORNL Photo 0101-23)

Fig. 39. Side View of Capsule No. 2 After Thermal Shock Test. (ORNL Photo 0103-23)

Fig. 40. Bottom End of Capsule No. 2 After Thermal Shock Test. (ORNL Photo 0107-73)

Fig. 41. Top End of Capsule No. 2 After Thermal Shock Test. (ORNL Photo 0105-73)

Fig. 42. Side View of Capsule No. 2 After Free Drop Test on Top End. (ORNL Photo 0167-73)

Fig. 43. Bottom End of Capsule No. 2 After Free Drop on Top End. (ORNL Photo 0163-73)

Fig. 44. Top End of Capsule No. 2 After Free Drop Test on Top End. (ORNL Photo 0165-73)

Fig. 45. Top End Closeup of Capsule No. 2 After Free Drop Test on Top End. (ORNL Photo 0206-73)

Fig. 46. Side View of Top End of Capsule No. 2 After Free Drop Test on Top End. (ORNL Photo 0367-73)

Fig. 47. Dye Penetrant Check of Crack on Top End of Capsule No. 2 After Free Drop Test on Top End. (ORNL Photo 0162-73)

Fig. 48. Positive Leak Test of Capsule No. 2 After Free Drop Test. (ORNL Photo 0161-73)

Fig. 49. Sketch of Deformation of Top End of Capsule No. 2 After Free Drop Test.

Fig. 50. Cross Section of Plasma Arc Weld of Impact Area After Free Drop Test on Top End of Capsule No. 2. (ORNL Photo 0422-73)

Fig. 51. Cross Section of Plasma Arc Weld 180° From Impact Area After Free Drop Test on Top End of Capsule No. 2. (ORNL Photo 0421-73)

Fig. 52. Side View of Capsule No. 2 After Free Drop Test on Bottom End. (ORNL Photo 0210-23)

Fig. 53. Bottom End of Capsule No. 2 After Free Drop Test on Bottom End. (ORNL Photo 0203-73)

Fig. 54. Closeup of Bottom End of Capsule No. 2 After Free Drop Test on Bottom End. (ORNL Photo 0204-73)

Fig. 55. Side View of Bottom End of Capsule No. 2 After Free Drop Test on Bottom End. (ORNL Photo 0361-73)

Fig. 56. Sketch of Deformation of Bottom End of Capsule No. 2 After Free Drop Test on Bottom End.

Fig. 57. Electron-Beam Weld Impact Area on Bottom End of Capsule No. 2. (ORNL Photo 0555-73)

Fig. 58. Percussion Testing Equipment. (ORNL Photo 0362-73)

Fig. 59. Side View of Capsule No. 2 After Percussion Test. (ORNL Photo 0369-73)

Fig. 60. Bottom End of Capsule No. 2 After Percussion Test. (ORNL Photo 0368-73)

Fig. 61. Top End of Capsule No. 2 After Percussion Test. (ORNL 0366-73)

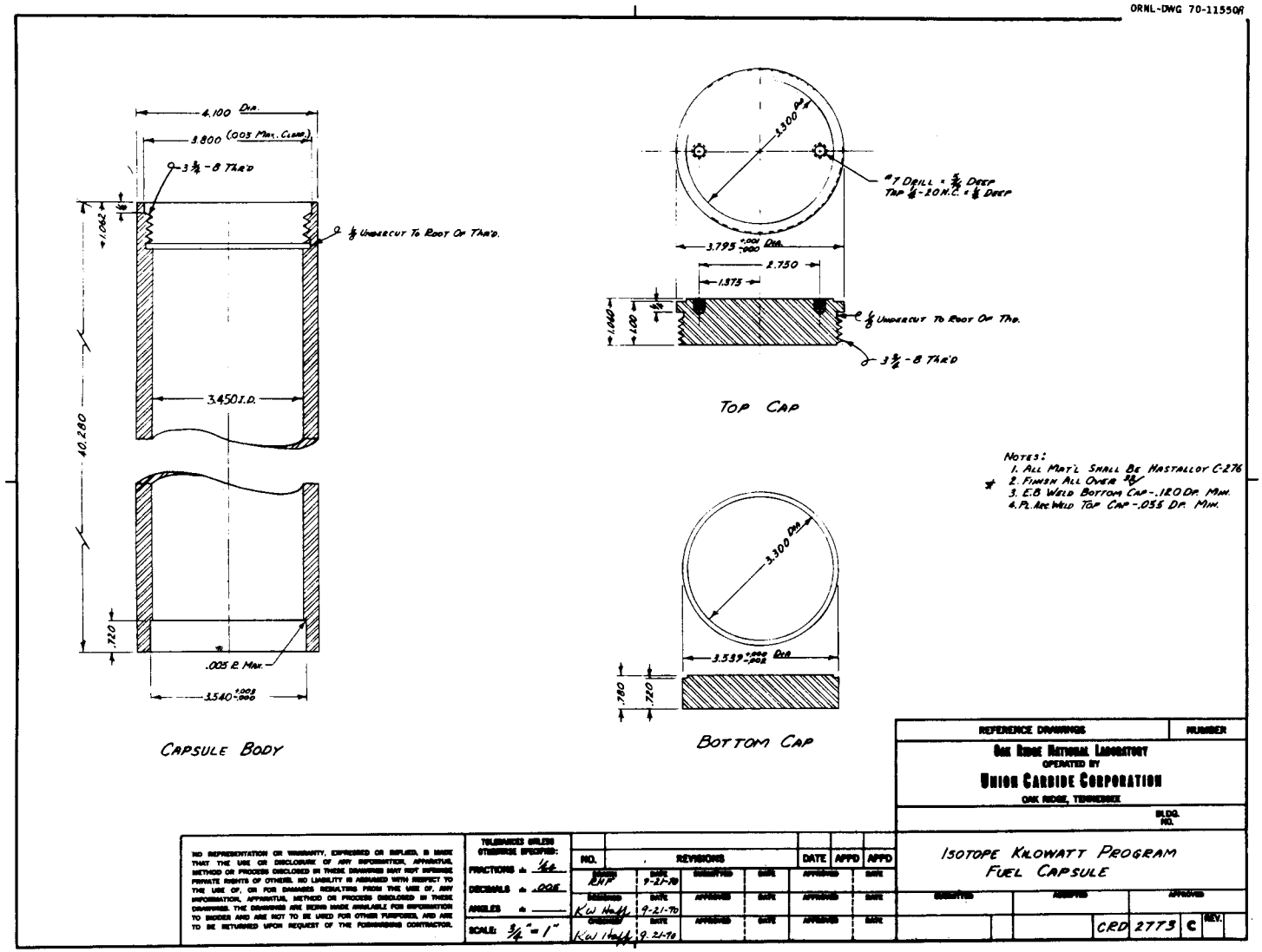

Fig. 1. Isotope Kilowatt Program Fuel Capsule.

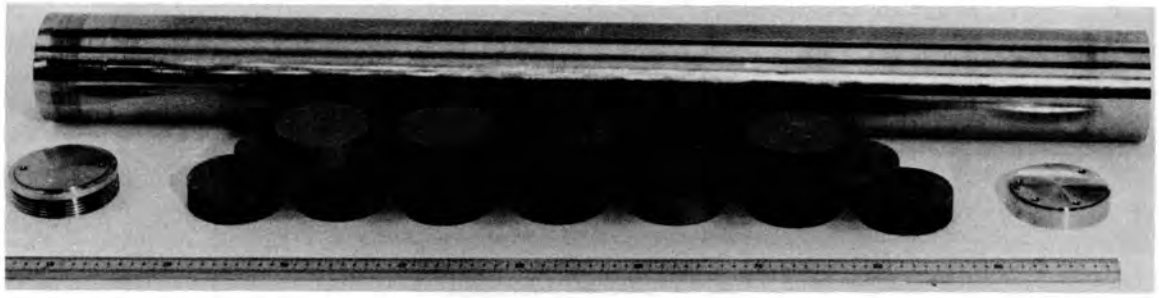

Fig. 2. IKP Capsule and Inert $SrTiO_3$ Pellets Prior to Assembly.

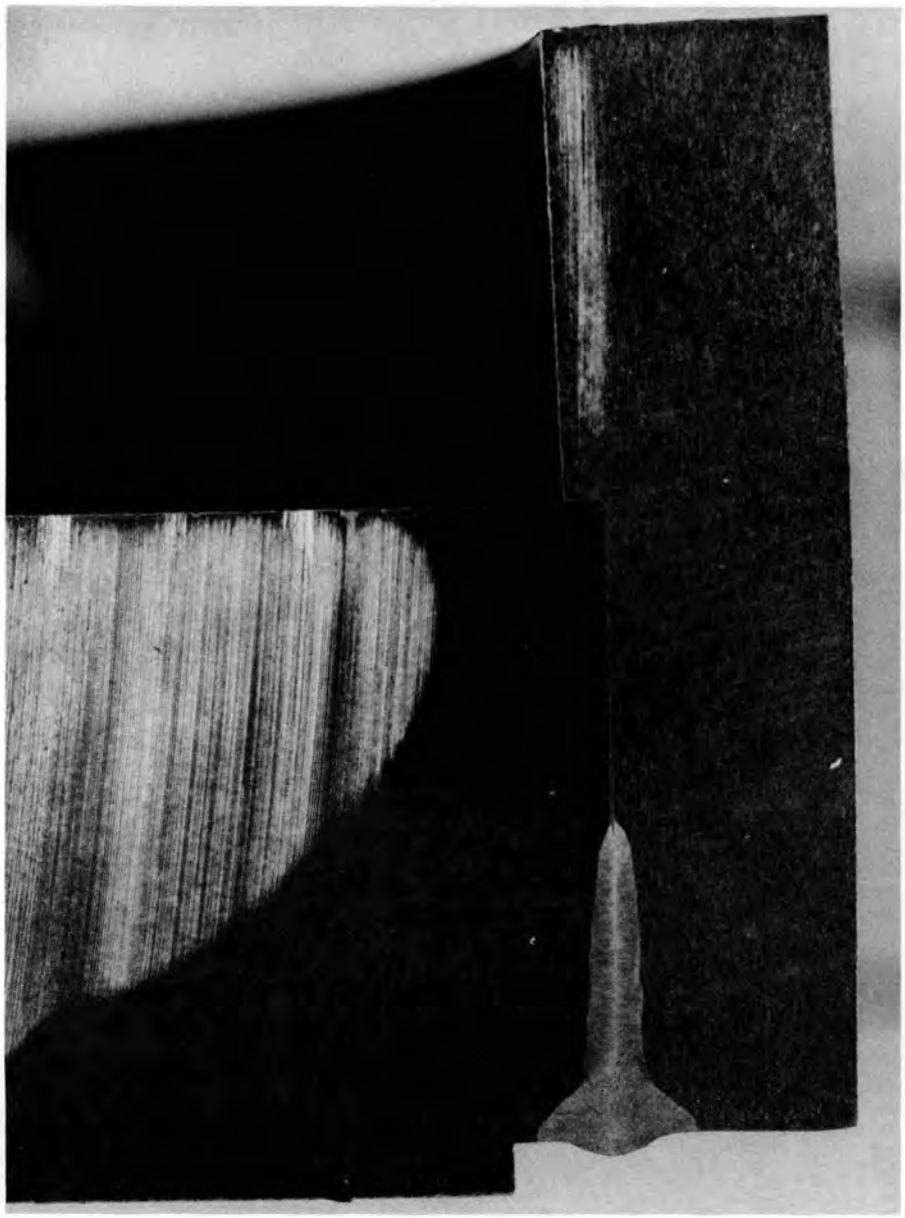

Fig. 3. Electron-Beam Weld of Bottom Cap on Capsule No. 2, 180° From Impact Area.

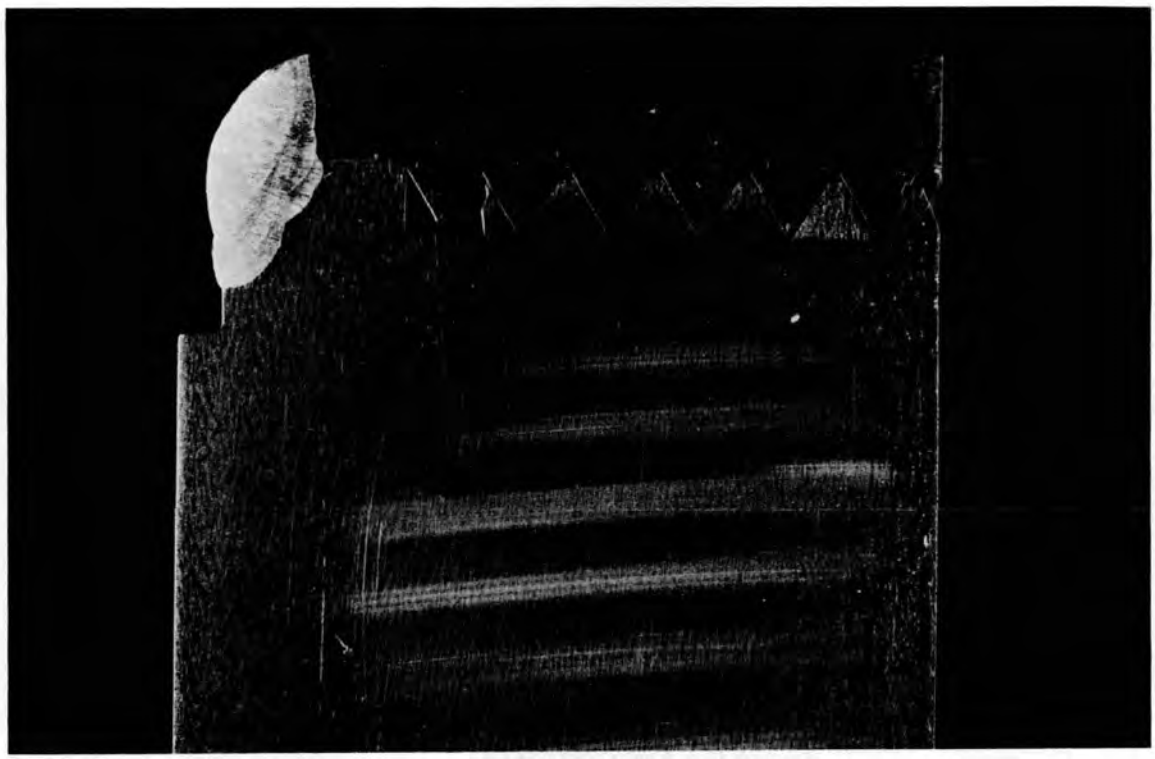

Fig. 4. Plasma Arc Weld of Test Top Cap, Right Section.

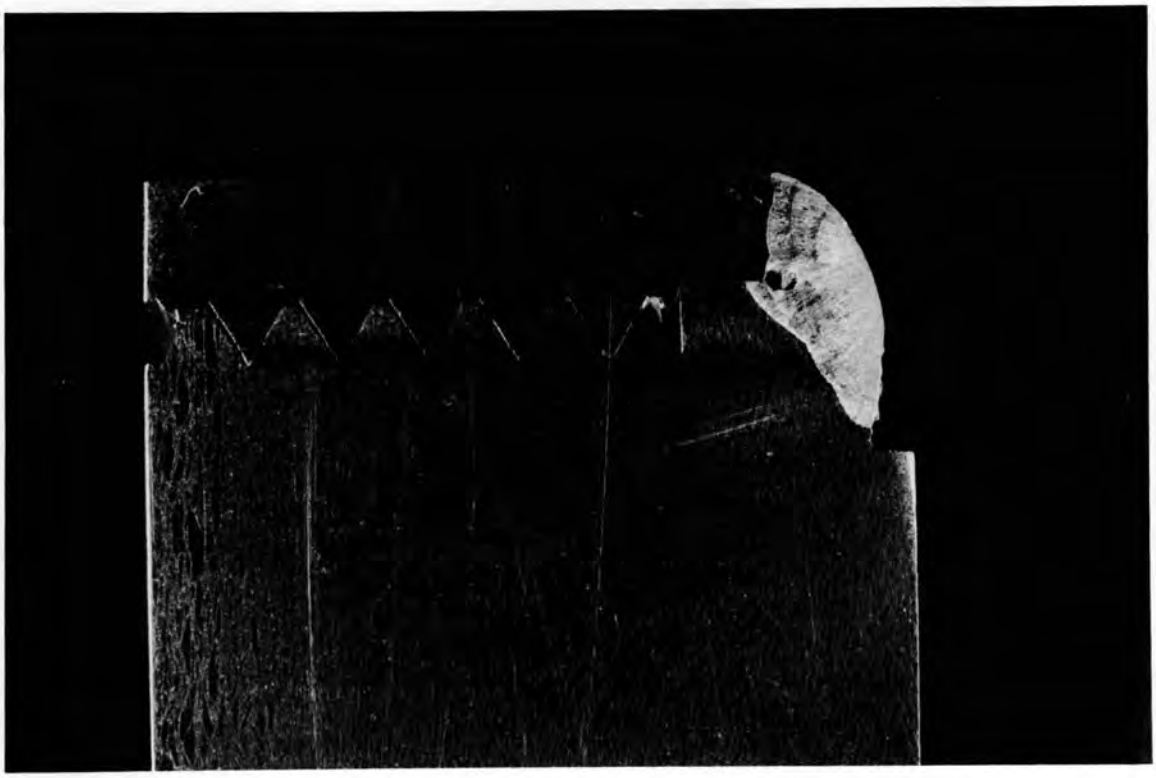

Fig. 5. Plasma Arc Weld of Test Top Cap, Left Section.

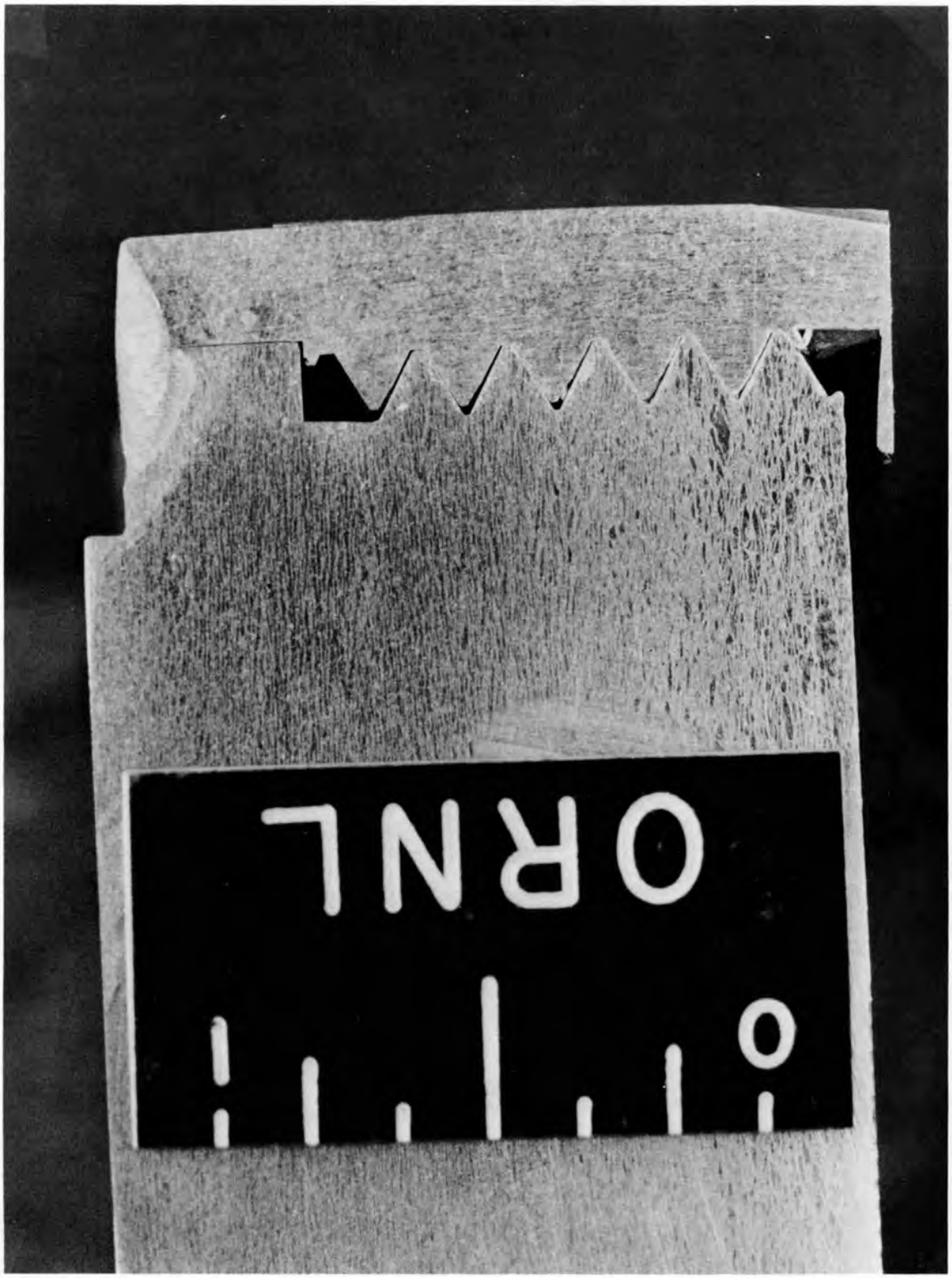

Fig. 6. Plasma Arc Weld of Top Cap on Capsule No. 2, Right Section.

IKP CAPSULE NO. 1
INITIAL 1-2-73
SIDE VIEW

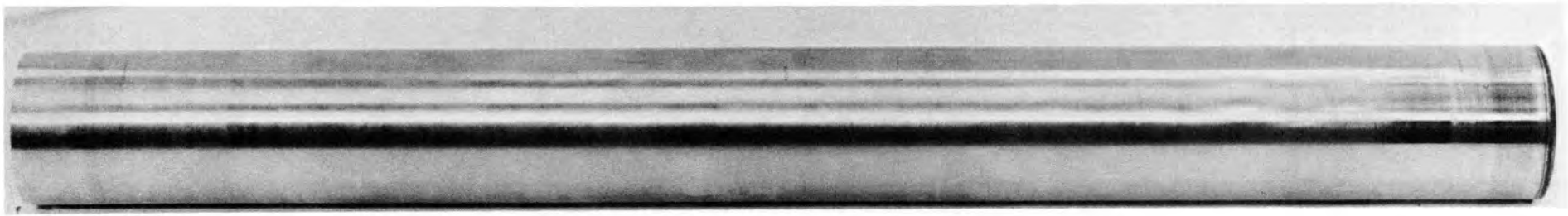

Fig. 7. Side View of Completed IKP Capsule No. 1.

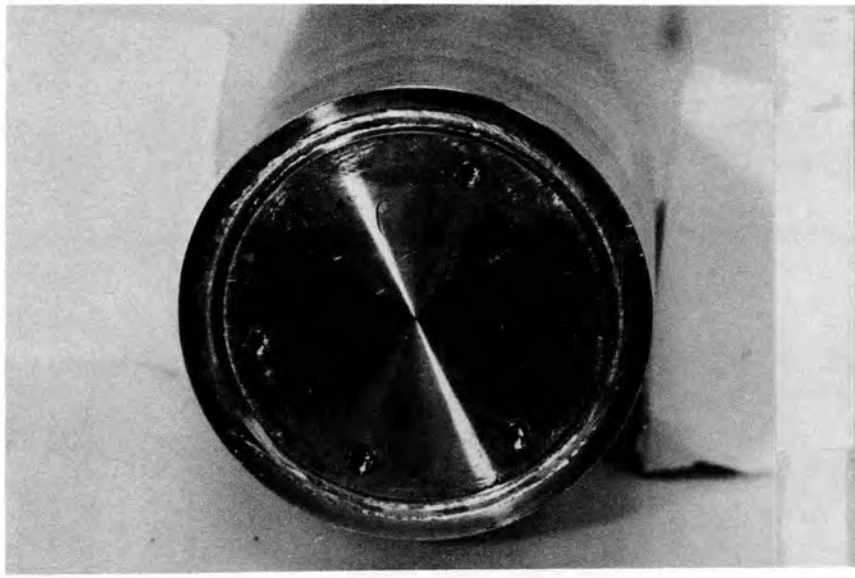

Fig. 8. Bottom View of Completed IKP Capsule No. 1.

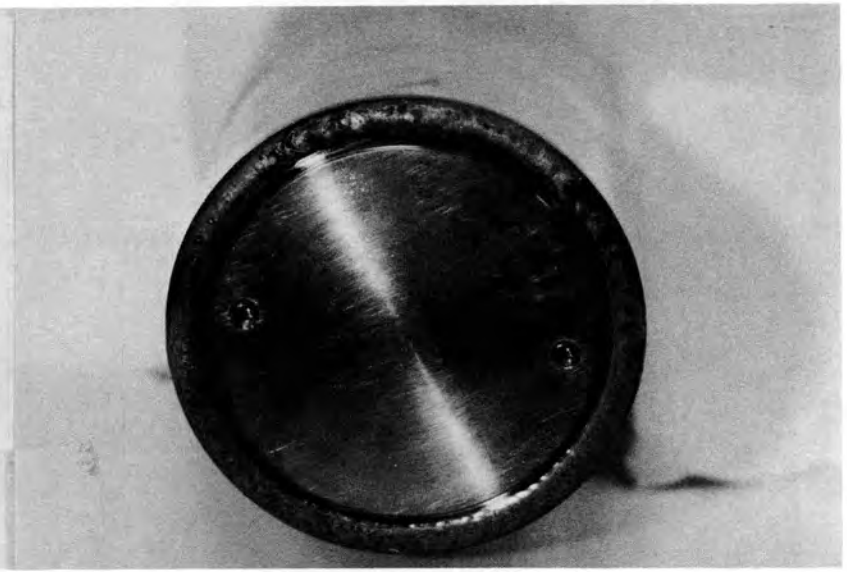

Fig. 9. Top View of Completed IKP Capsule No. 1.

IKP CAPSULE NO. 2
INITIAL 1-2-73

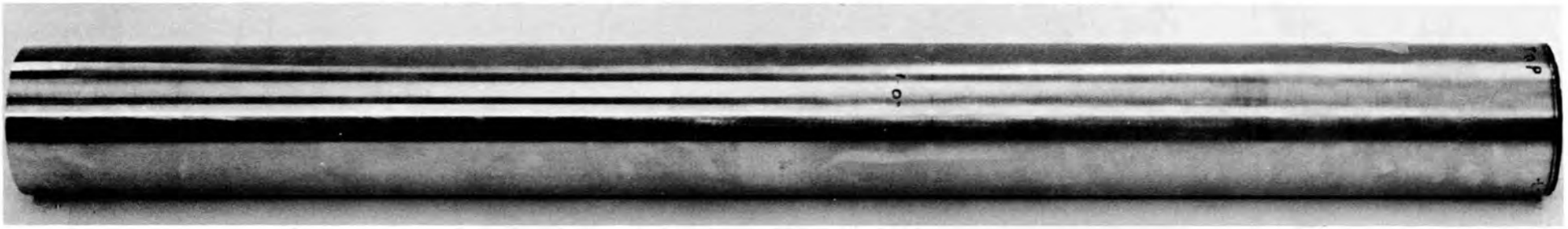

Fig. 10. Side View of Completed IKP Capsule No. 2.

Fig. 11. Bottom View of Completed IKP Capsule No. 2.

Fig. 12. Top View of Completed IKP Capsule No. 2.

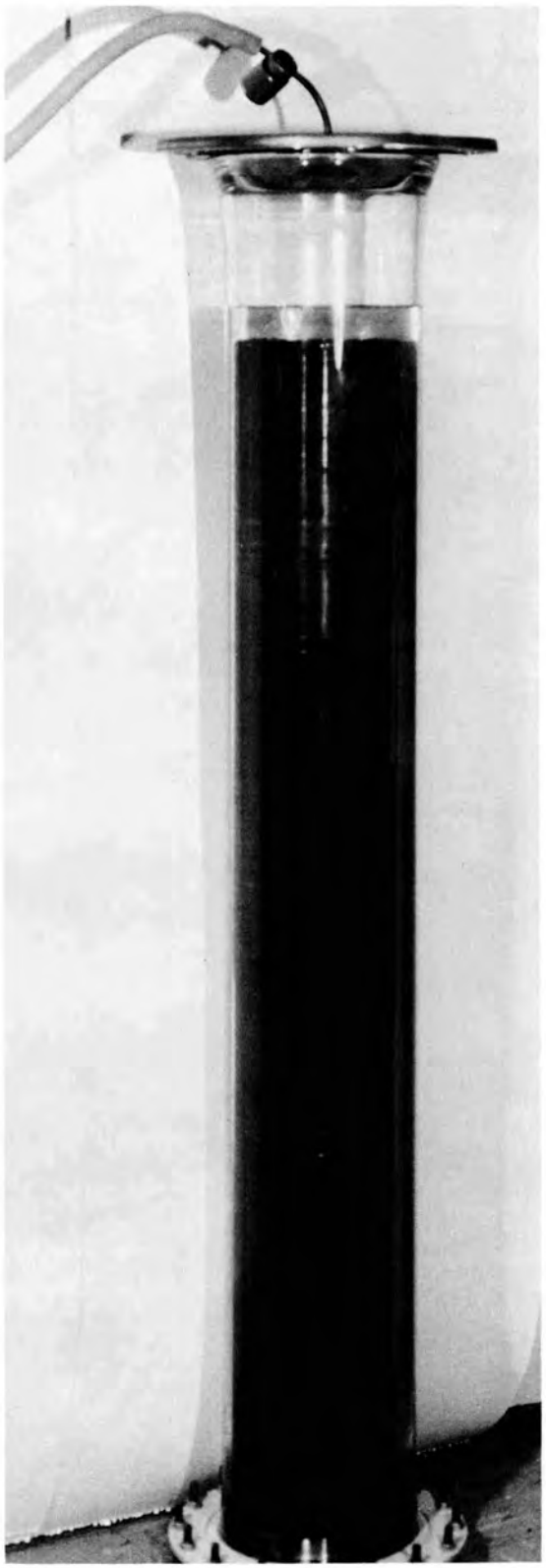

Fig. 13. Vacuum Leak Testing Equipment.

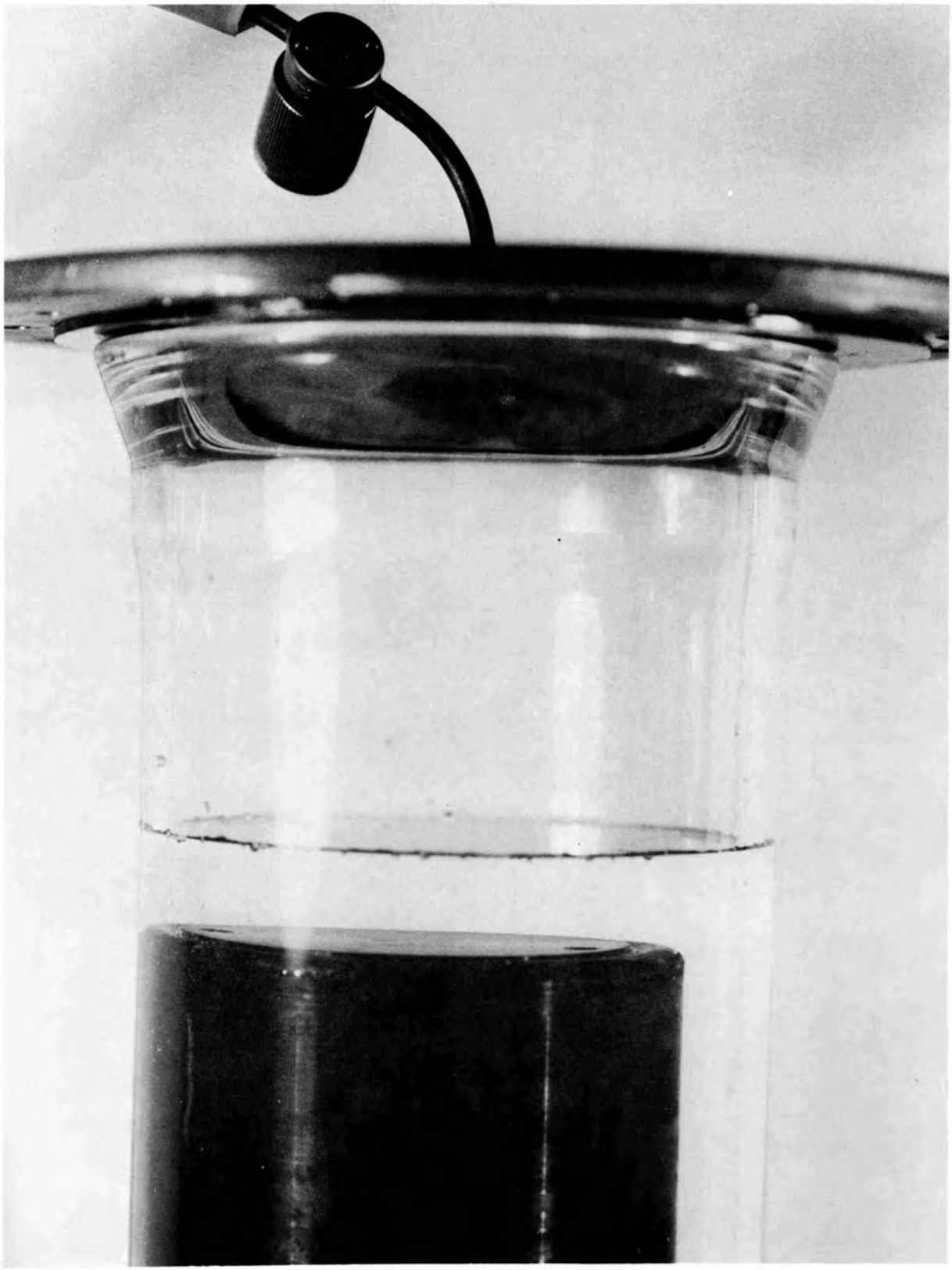

Fig. 14. Closeup of a Negative Vacuum Leak Test.

IKP CAPSULE NO. 1
SIDE VIEW

POST HEAT TREAT 1-4-73
PRE HYDRO PRESSURE TEST

Fig. 15. Side View of Capsule No. 1 After Heat Treatment Test.

Fig. 16. Bottom End of Capsule No. 1 After Heat Treatment Test.

Fig. 17. Top End of Capsule No. 1 After Heat Treatment Test.

IKP CAPSULE NO. 2
SIDE VIEW

POST HEAT TREAT 1-8-73
PRE HEATING TEST

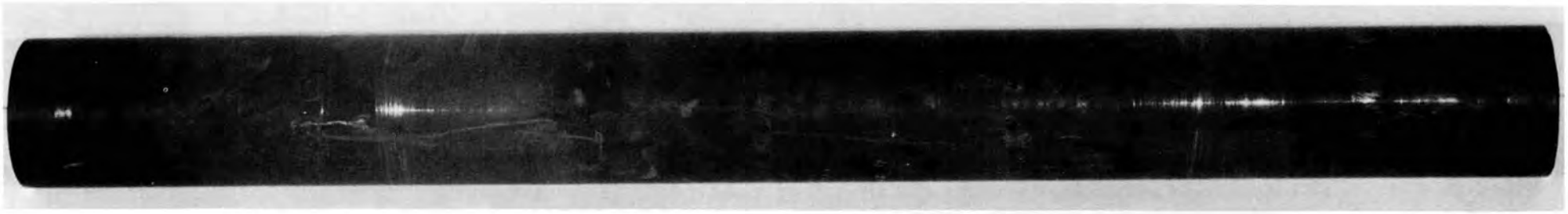

Fig. 18. Side View of Capsule No. 2 After Heat Treatment Test.

Fig. 19. Bottom End of Capsule No. 2 After Heat Treatment Test.

Fig. 20. Top End of Capsule No. 2 After Heat Treatment Test.

Fig. 21. Side View of Capsule No. 1 After Hydrostatic Pressure Test.

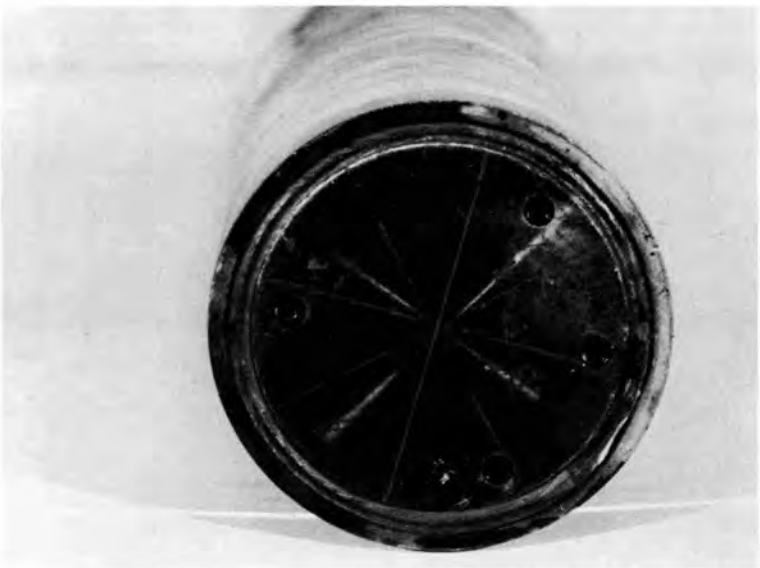

Fig. 22. Bottom End of Capsule No. 1 After Hydrostatic Pressure Test.

Fig. 23. Top End of Capsule No. 1 After Hydrostatic Pressure Test.

Fig. 24. Side View of Top End of Capsule No. 1 After Hydrostatic Pressure Test.

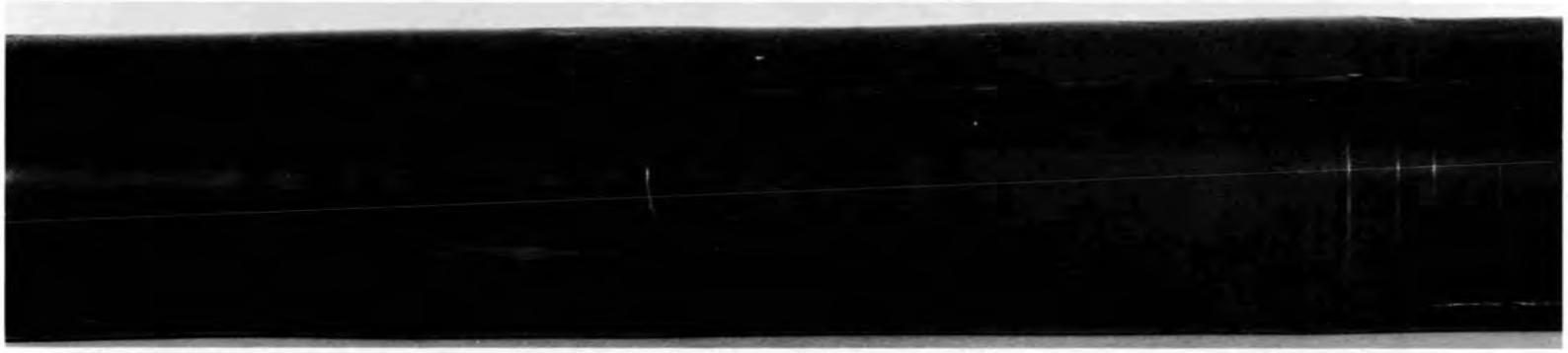

Fig. 25. Side View of Middle Section of Capsule No. 1 After Hydrostatic Pressure Test.

Fig. 26. Side View of Bottom End of Capsule No. 1 After Nydrostatic Pressure Test.

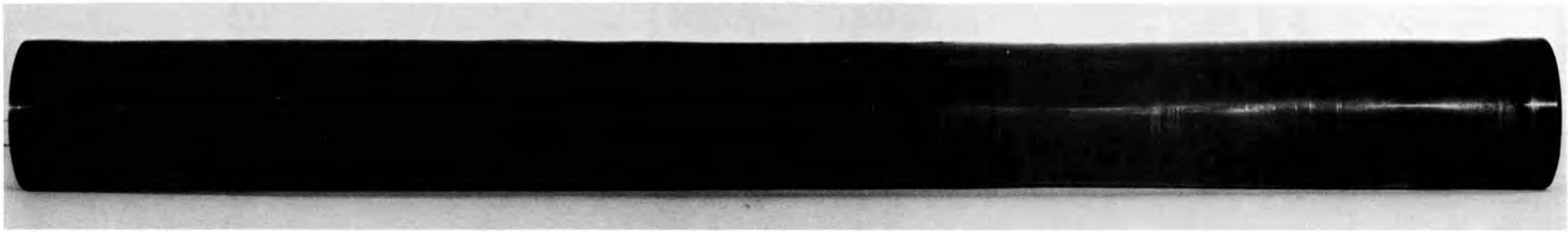

Fig. 27. Side View of Capsule No. 1 After Immersion Test.

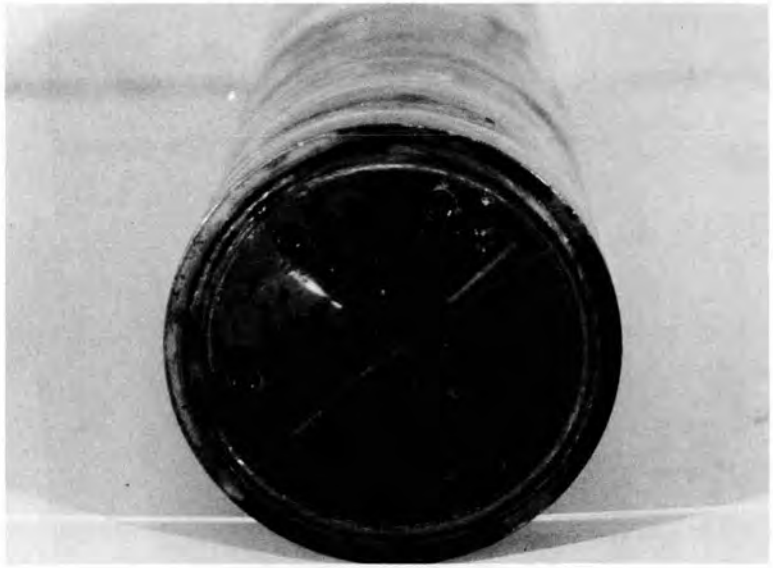

Fig. 28. Bottom End of Capsule No. 1 After Immersion Test.

Fig. 29. Top End of Capsule No. 1 After Immersion Test.

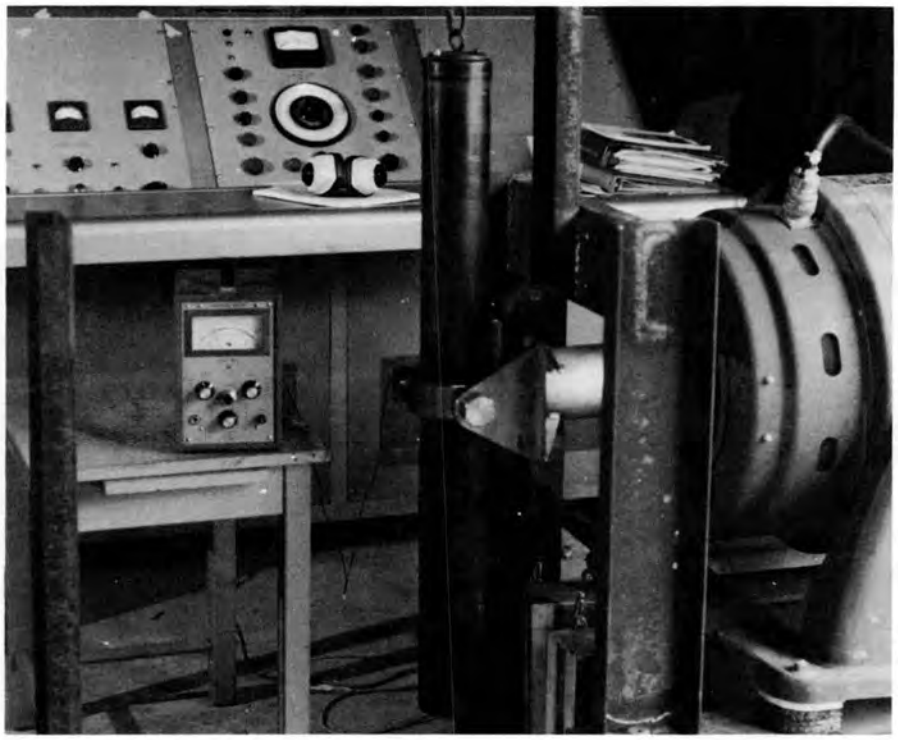

Fig. 30. Vibration Testing Equipment.

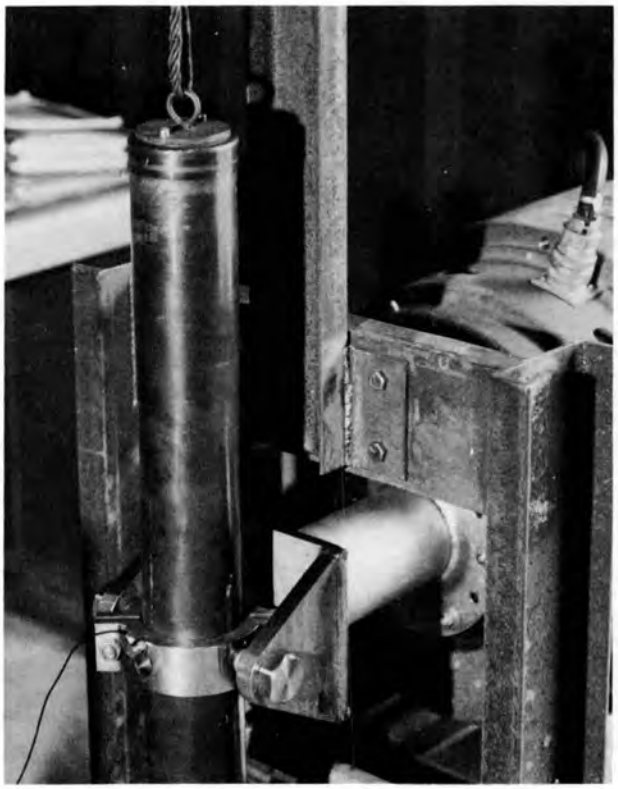

Fig. 31. Vibration Testing Equipment.

IKP CAPSULE NO. 1
SIDE VIEW 4-3-73
POST VIBRATION TEST

Fig. 32. Side View of Capsule No. 1 After Vibration Test.

Fig. 33. Bottom End of Capsule No. 1 After Vibration Test.

Fig. 34. Top End of Capsule No. 1 After Vibration Test.

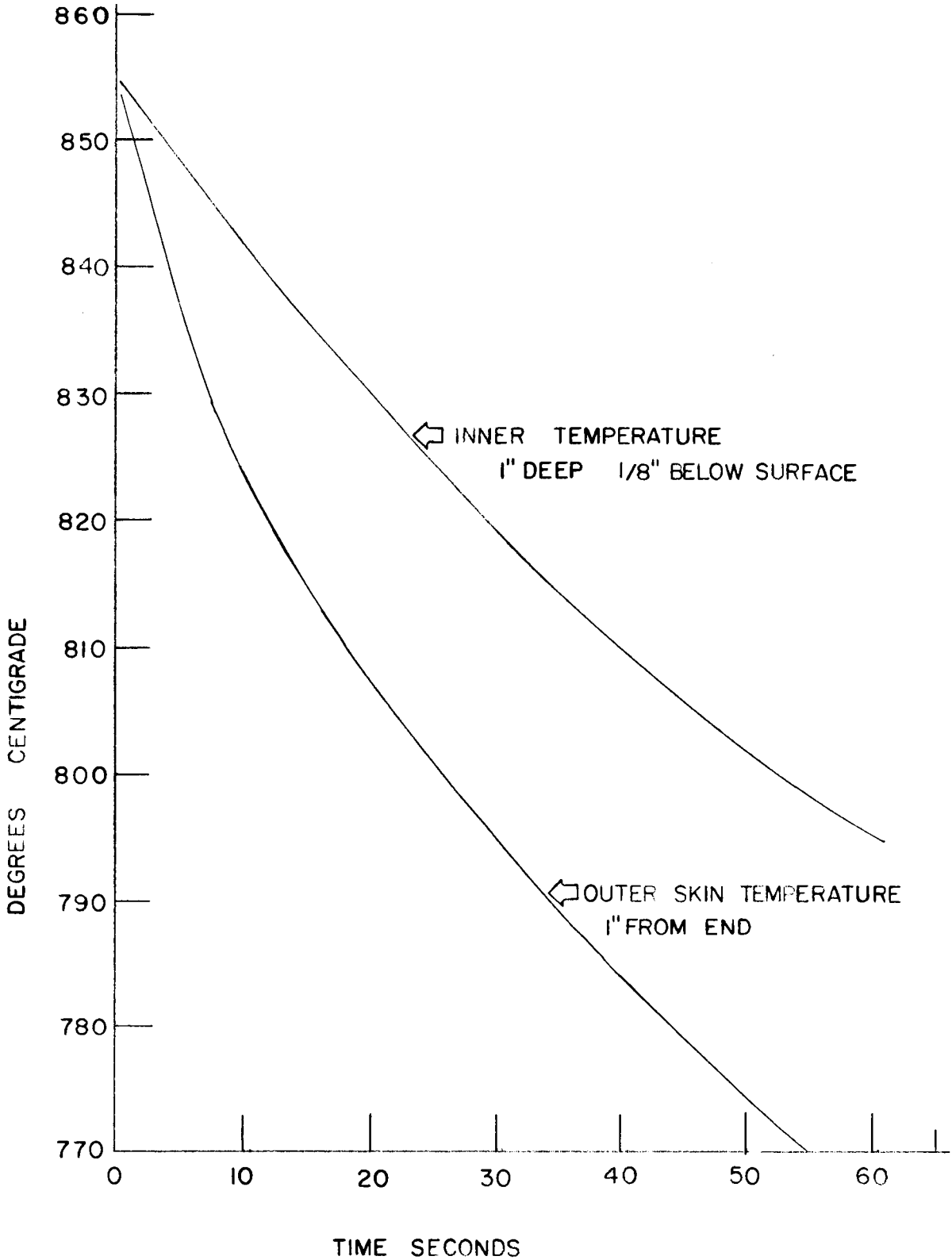

Fig. 35. Air Cool-Down Temperature for Steel Test Piece.

IKP CAPSULE NO. 2
SIDE VIEW

POST HEATING TEST 1-9-73
PRE THERMAL SHOCK TEST

Fig. 36. Side View of Capsule No. 2 After Heat Test.

Fig. 37. Bottom End of Capsule No. 2 After Heat Test.

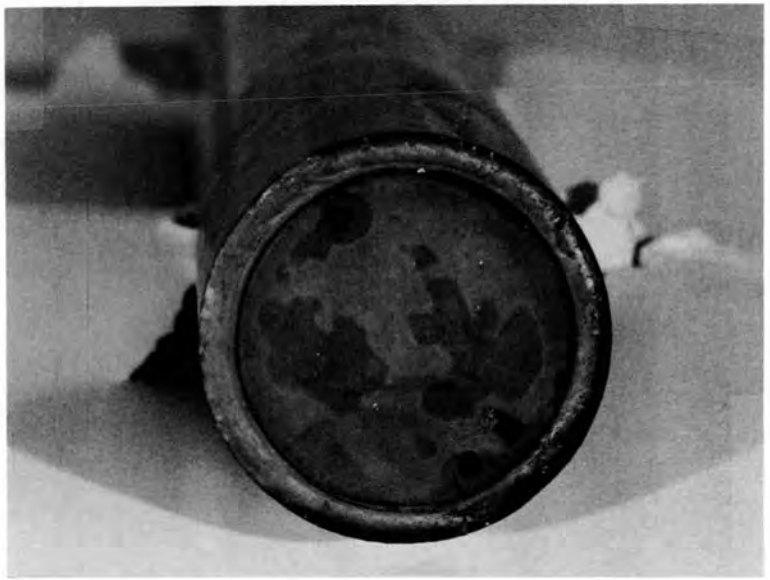

Fig. 38. Top End of Capsule No. 2 After Heat Test.

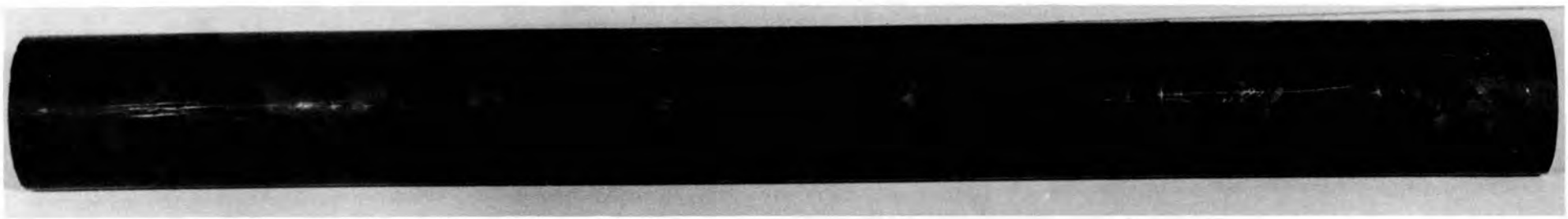

Fig. 39. Side View of Capsule No. 2 After Thermal Shock Test.

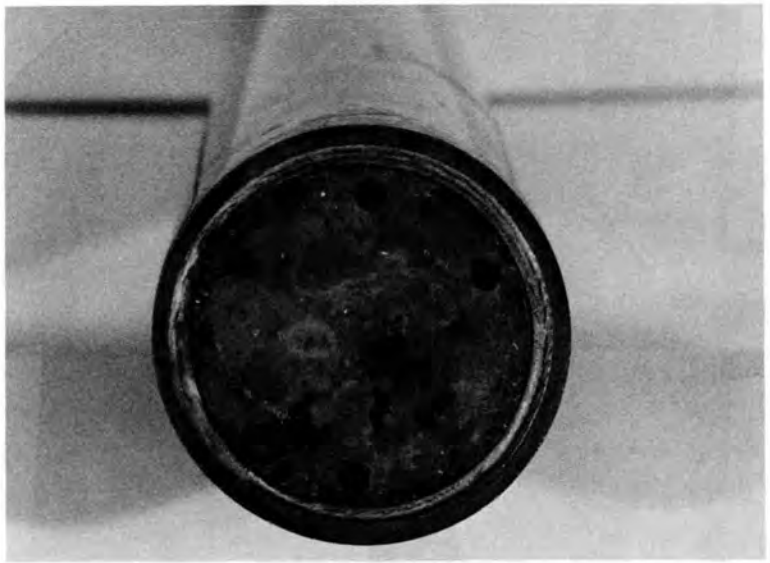

Fig. 40. Bottom End of Capsule No. 2 After Thermal Shock Test.

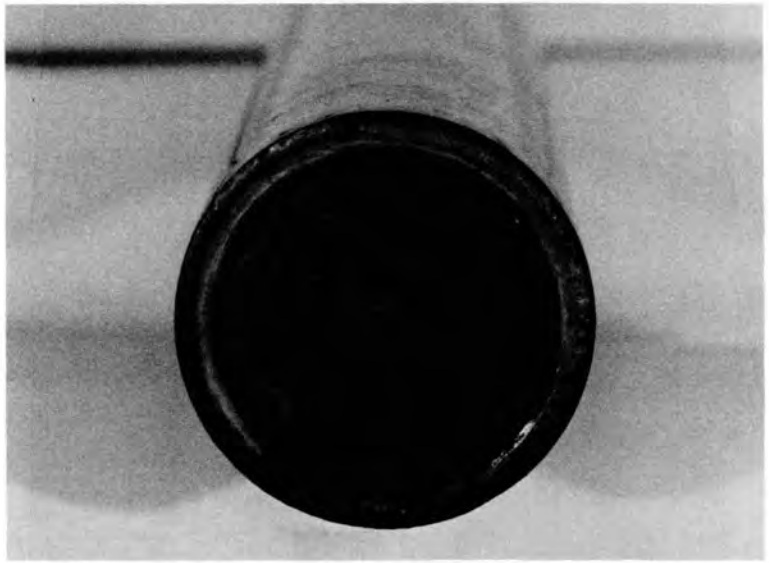

Fig. 41. Top End of Capsule No. 2 After Thermal Shock Test.

Fig. 42. Side View of Capsule No. 2 After Free Drop Test on Top End.

Fig. 43. Bottom End of Capsule No. 2 After Free Drop Test on Top End.

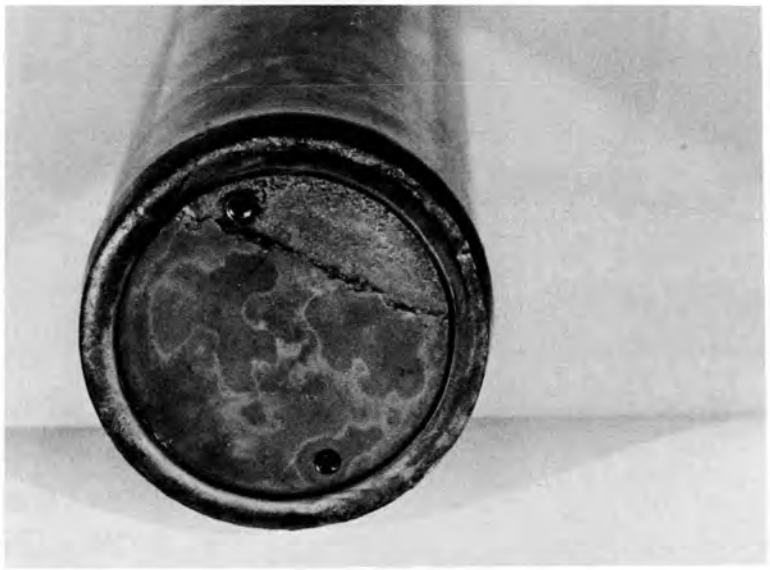

Fig. 44. Top End of Capsule No. 2 After Free Drop Test on Top End.

Fig. 45. Top End Closeup of Capsule No. 2
After Free Drop Test on Top End.

Fig. 46. Side View of Top End of Capsule No. 2
After Free Drop Test on Top End.

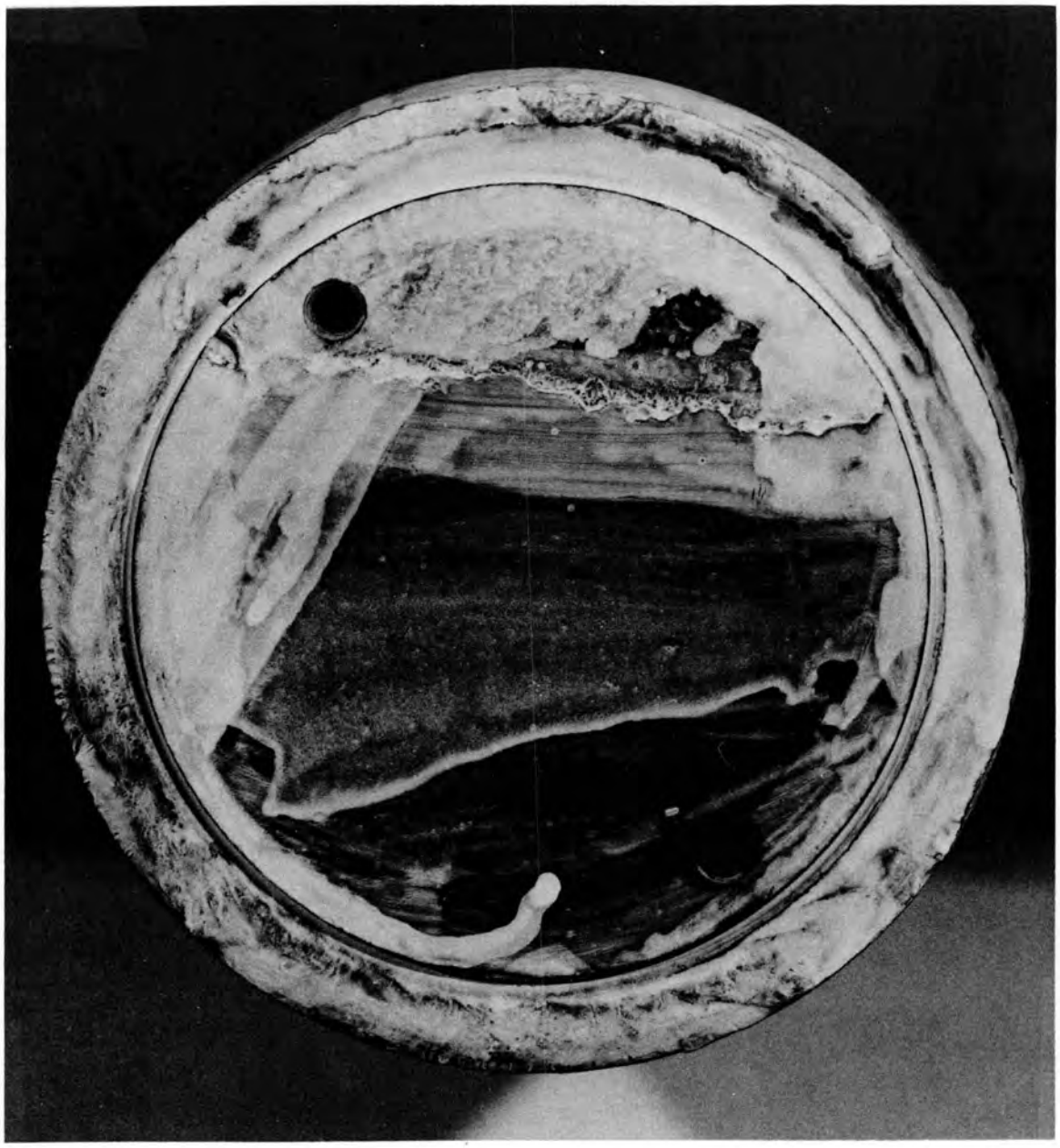

Fig. 47. Dye Penetrant Check of Crack on Top End of Capsule No. 2 After Free Drop Test on Top End.

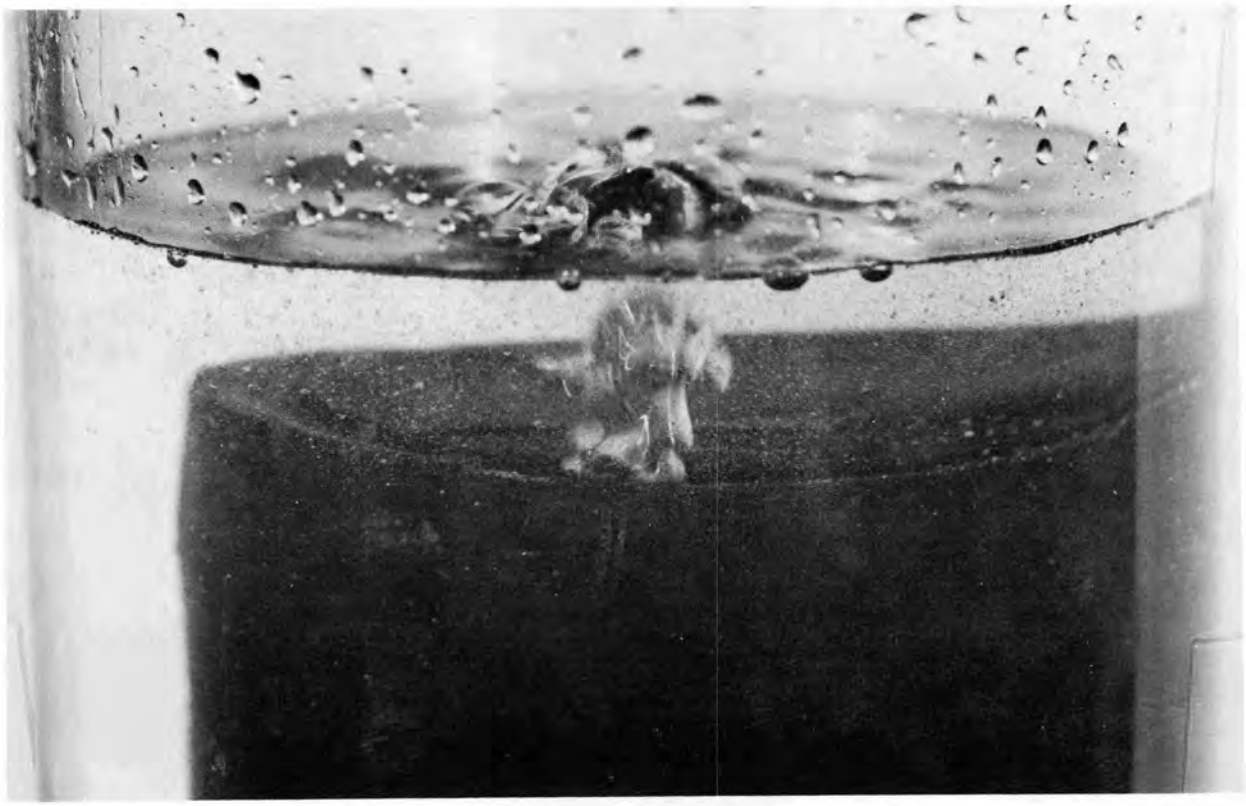

Fig. 48. Positive Leak Test of Capsule No. 2 After Free Drop Test.

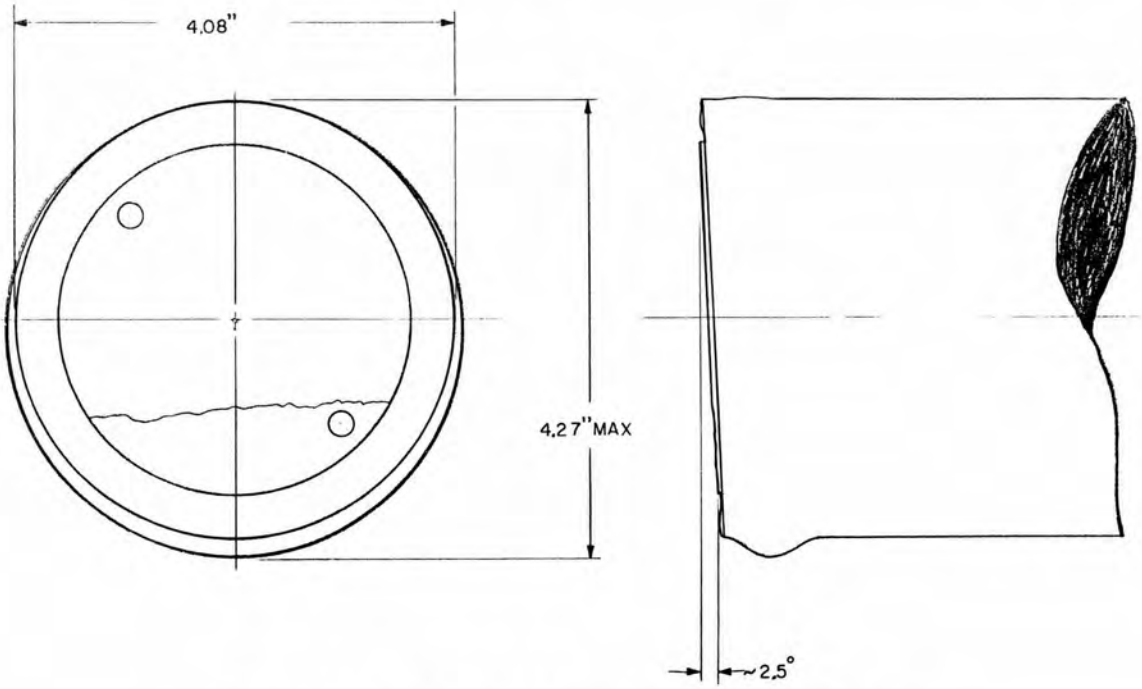

Fig. 49. Sketch of Deformation of Top End of Capsule No. 2 After Free Drop Test.

Fig. 50. Cross Section of Plasma Arc Weld of Impact Area After Free Drop Test on Top End of Capsule No. 2.

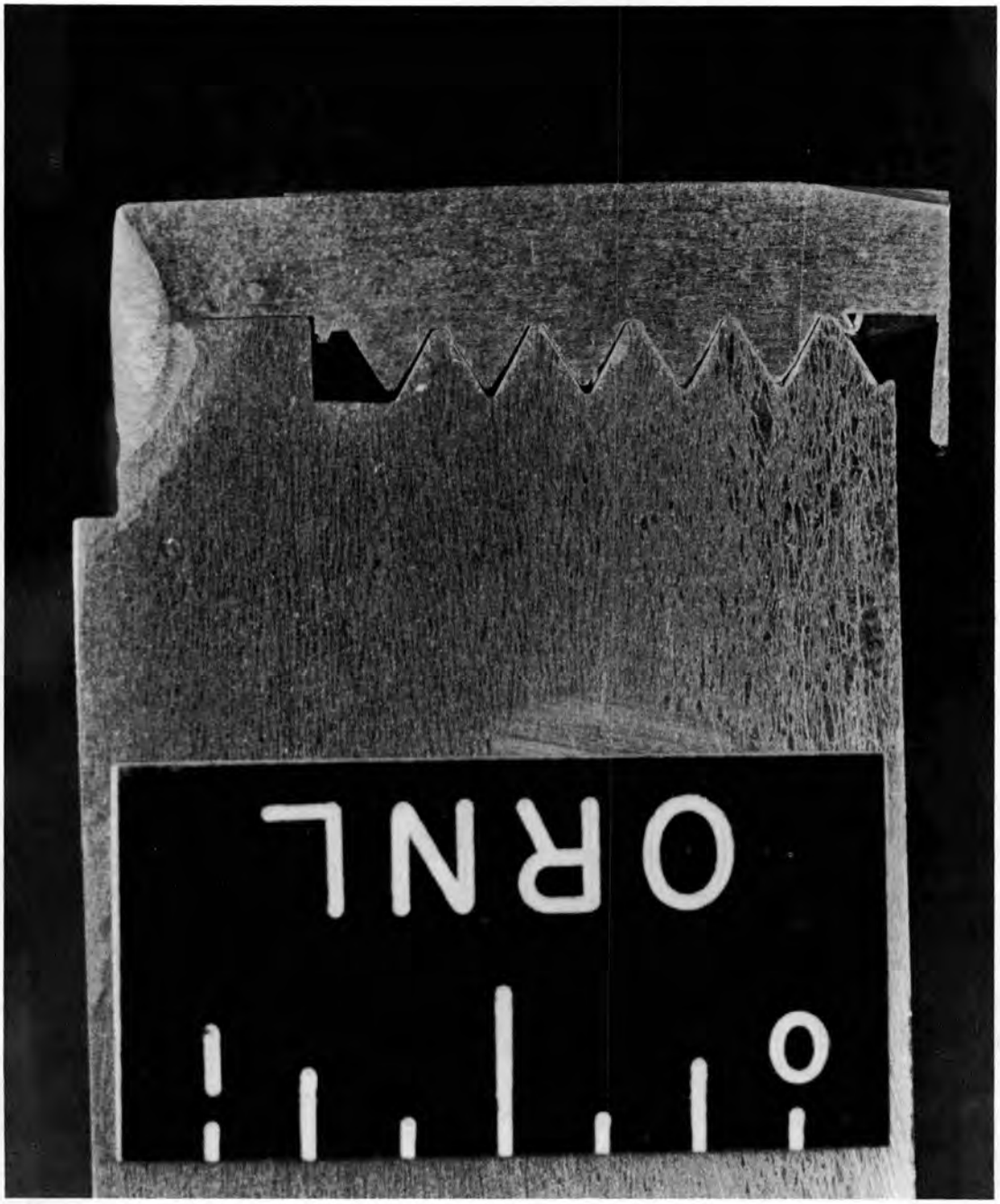

Fig. 51. Cross Section of Plasma Arc Weld 180° From Impact Area After Free Drop Test on Top End of Capsule No. 2.

Fig. 52. Side View of Capsule No. 2 After Free Drop Test on Bottom End.

Fig. 53. Bottom End of Capsule No. 2 After Free Drop Test on Bottom End.

Fig. 54. Closeup of Bottom End of Capsule No. 2
After Free Drop Test on Bottom End.

Fig. 55. Side View of Bottom End of Capsule No. 2
After Free Drop Test on Bottom End.

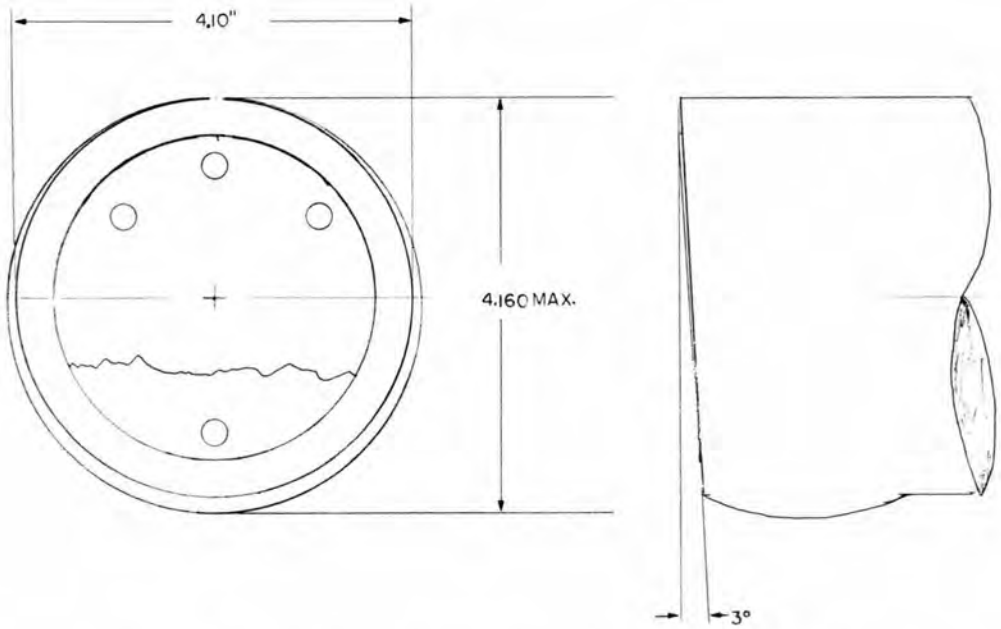

Fig. 56. Sketch of Deformation of Bottom End of Capsule No. 2 After Free Drop Test on Bottom End.

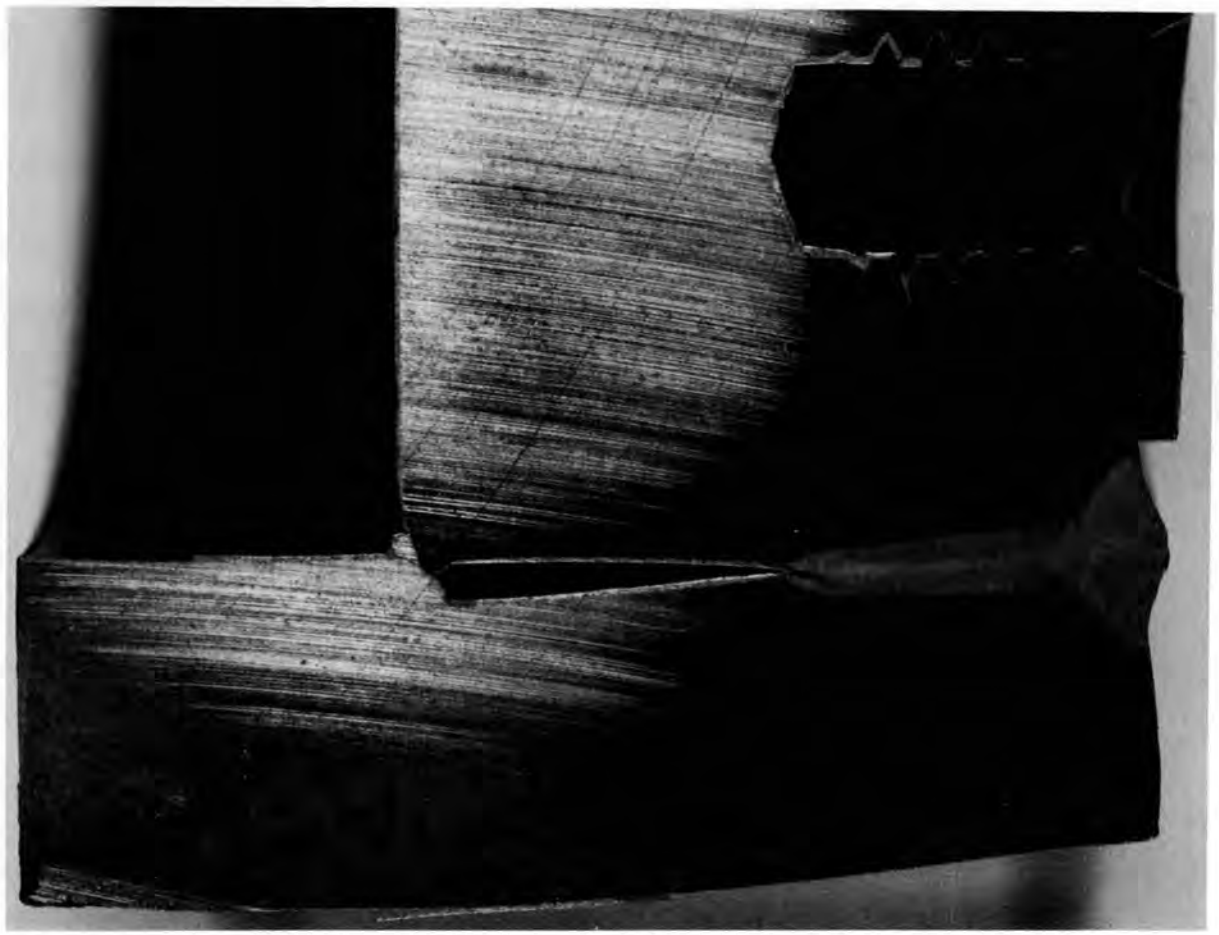

Fig. 57. Electron-Beam Weld Impact Area on Bottom End of Capsule No. 2.

Fig. 58. Percussion Testing Equipment.

IKP CAPSULE NO. 2
SIDE VIEW 2-1-73
POST PERCUSSION TEST

Fig. 59. Side View of Capsule No. 2 After Percussion Test.

Fig. 60. Bottom End of Capsule No. 2 After Percussion Test.

Fig. 61. Top End of Capsule No. 2 After Percussion Test.

APPENDIX IV

Fabrication Check Sheets

1. Chemical Analysis and Mechanical Tests for 1-in.-thick Plate
2. Chemical Analysis and Mechanical Tests for 2-in.-thick Plate
3. Chemical Analysis and Mechanical Tests for 4-1/2-in.-diam Rod
4. Parts Inspection Form for Capsule No. 1
5. Parts Inspection Form for Capsule No. 2
6. Dimensional Inspection Print
7. Ultrasonic Inspection of Bottom Cap to Capsule Weldments

CERTIFIED REPORT OF CHEMICAL ANALYSIS AND MECHANICAL TESTS

INVOICE NO: 22420000 | B O | SUP | DATE ENTERED: 061272

SOLD TO (BUYER)
UNION CARBIDE CORP
P O BOX P ACCTS PAY DEPT
OAK RIDBE TENN 37830

CABOT
STELLITE DIVISION
CABOT CORPORATION
1020 West Park Avenue
Kokomo, Indiana 46901

SHIP TO
U S ATOMIC ENERGY COMMISSION
C/O UNION CARBIDE CORP
PLT X10
OAK RIDGE TENN 37830

77X04921 2-2 ← CUSTOMER'S REFERENCE

QUANTITY ORDERED: 1PC
QUANTITY SHIPPED: 1 pc.

1 X 12 X 32 LG PLATE HASTELLOY ALLOY C-276

REMARKS
1 THIS MATERIAL HAS PASSED THE BEND TEST AND IS CAPABLE OF MEETING THE STRESS RUPTURE REQUIREMENTS PER SPECIFICATION.
2 THIS MATERIAL IS CAPABLE OF MEETING THE STRESS RUPTURE REQUIREMENTS PER SPECIFICATION.
3 THIS MATERIAL IS CERTIFIED TO THE CHEMISTRY ONLY. THE ABOVE PROPERTIES ARE REPORTED FOR INFORMATION.
4 TEST SPECIMEN OBTAINED FROM A FORGED TEST INGOT THAT IS PROPERLY HEAT TREATED.

	HEAT NO	PIECES	Cr	W	Fe	C	Si	Co	Ni	Mn	Cb+Ta	V	Mo	P	S
1	2760-2-3	044	15.16	3.79	6.18	.006	<.01	.91	bal	.45		.21	15.84	.014	.010
2															
3															
4															
5															
6															

	Al	Ti	B	Cu	Zr	Ta	Mg	O_2	H_2	N_2
1										
2										
3										
4										
5										
6										

REMEMBER
Stellite Div. will be shut down for vacation from July 22 to Aug. 7

TENSILE TEST AT ROOM TEMPERATURE

	ULTIMATE PSI	2% YIELD PSI	02% YIELD PSI	% ELONG IN 4D	% R A
1	113,650	52,150			63.0
2					
3					

TENSILE TEST AT °F

	ULTIMATE PSI	2% YIELD PSI	02% YIELD PSI	% ELONG IN	%R A
1					
2					
3					

STRESS RUPTURE

	TEST TEMP. (°F)	STRESS PSI	HOURS	% ELONG IN	ANNEALED HARDNESS	AGED HARDNESS	GRAIN SIZE	I G A DEPTH
1								
2								
3								

THIS IS TO CERTIFY THAT THE ORIGINAL OF THIS REPORT HAS BEEN PROPERLY SIGNED AND NOTARIZED

CERTIFIED BY: S J Metz
DATE: June 16,1972
m

SUBSCRIBED AND SWORN TO BEFORE ME
NOTARY: Mary Helen Martin
My Commission Expires Feb. 3, 1973

S-779E

CERTIFIED REPORT OF CHEMICAL ANALYSIS AND MECHANICAL TESTS

INVOICE NO 22419 B.O. 0000 SUP DATE ENTERED 06 12 72

SOLD TO (BUYER)
UNION CARBIDE CORP
P O BOX P ACCTS PAY DEPT
OAK RIDGE TENN 37830

CABOT
STELLITE DIVISION
CABOT CORPORATION
1020 West Park Avenue
Kokomo Indiana 46901

SHIP TO
U S ATOMIC ENERGY COMMISSION
C/O UNION CARBIDE CORP
PLT X10
OAK RIDGE TENN 37830

77X04921 1-2 ← CUSTOMER'S REFERENCE

QUANTITY ORDERED: 1 PC
QUANTITY SHIPPED: 1 pc.

2 X 12 X 16 LG PLATE HASTELLOY ALLOY C-276

REMARKS:
1. THIS MATERIAL HAS PASSED THE BEND TEST AND IS CAPABLE OF MEETING THE STRESS RUPTURE REQUIREMENTS PER SPECIFICATION.
2. THIS MATERIAL IS CAPABLE OF MEETING THE STRESS RUPTURE REQUIREMENTS PER SPECIFICATION.
3. THIS MATERIAL IS CERTIFIED TO THE CHEMISTRY ONLY. THE ABOVE PROPERTIES ARE REPORTED FOR INFORMATION.
4. TEST SPECIMEN OBTAINED FROM A FORGED TEST INGOT THAT IS PROPERLY HEAT TREATED.

	HEAT NO	PIECES	Cr	W	Fe	C	Si	Co	Ni	Mn	Cb+Ta	V	Mo	P	S
1	2760-1-3283		15.75	3.06	5.40	.013	<.01	1.72	bal	.51		.26	15.85	.010	.007
2															
3															
4															
5															
6															

	Al	Ti	B	Cu	Zr	Ta	Mg	O_2	H_2	N_2
1										
2										
3										
4										
5										
6										

REMEMBER
Stellite Div. will be shut down for vacation from July 22 to Aug. 7

TENSILE TEST AT ROOM TEMPERATURE

	ULTIMATE PSI	2% YIELD PSI	02% YIELD PSI	% ELONG IN 4D	% R A
1	118,750	51,850		57.0	
2					
3					

TENSILE TEST AT °F

	ULTIMATE PSI	2% YIELD PSI	02% YIELD PSI	% ELONG IN	%R A
1					
2					
3					

STRESS RUPTURE

	TEST TEMP (°F)	STRESS PSI	HOURS	% ELONG IN	ANNEALED HARDNESS	AGED HARDNESS	GRAIN SIZE	I G A DEPTH
1								
2								
3								

THIS IS TO CERTIFY THAT THE ORIGINAL OF THIS REPORT HAS BEEN PROPERLY SIGNED AND NOTARIZED

CERTIFIED BY

DATE June 16,1972

SUBSCRIBED AND SWORN TO BEFORE ME

NOTARY

My Commission Expires Feb. 3, 1973

S-779E

ATEK METALS CENTER INC.
A POLYMET CORP. SUBSIDIARY
10597 CHESTER ROAD
CINCINNATI, OHIO 45215
(513) 771-6810

CERTIFICATE OF TEST

TO: Union Carbide Corp.

CUSTOMER ORDER NO. 77X-04922
QUANTITY 1 pc.
DATE 8-18-72

ALLOY Hast C-276 SPECIFICATION -----
HEAT NO. 2760-2-3202 SIZE 4-1/2" rd. x 48" ATEK NO. AT 72471

CHEMICAL COMPOSITION (Ladle Analysis)	Cr	W	Fe	C	Si	Co	Ni	Mn	Cb + Ta	Mo	P	S	Al	Ti	B	Cu	V
	15.52	3.59	5.97	.012	*.01	1.75	bal.	.45		15.52	.014	*.005					.23

MECHANICAL TEST	Mechanical Properties								Stress Rupture							
	Heat Treatment	Temp. °F	UTS Ksi	.2% Yield Ksi	.02% Yield Ksi	El %	Ra %	Hard Rc	Heat Treatment	Temp. °F	Load Ksi	Life Hrs.	El %	Ra %	Hard Rc	Type Bar
Z1576 Heff		RT	103.85	46.80		52.1										

CONDITION SHIPPED	ANNEALED HARDNESS AGED HARDNESS	GRAIN SIZE	BEND TEST	I.G.A. DEPTH

☐ 1. This material has passed the bend test and is capable of meeting the stress rupture requirements per specification.

☐ 2. This material is capable of meeting the stress rupture requirements per specification.

☐ 3. This material has been annealed and cooled in a dry hydrogen atmosphere.

MILL SOURCE: Stellite
Test specimen obtained from a forged test ingot that is properly heat treated.

We certify that this data is correct and true to our knowledge and belief.

ATEK METALS CENTER

MATERIALS ENGINEER

DATE

CHARGER PRESS, INC

Dimensional Measurements

Isotope Kilowatt Program Fuel Capsule

Dimensional measurements for the IKP fuel capsule are taken in accordance with the following format:

Each capsule shall be marked to define top, bottom, middle, 1 in. from either end, and radial positions at 0°, 45°, 90°, 135°, 180°, 225°, 270°, and 315°.

The design dimension and tolerance for each dimension to be recorded shall be shown adjacent to the recording position on the data sheet to provide greater ease of comparison.

The following dimensional measurements shall be made:

Radial — At middle of capsule and 1 in. from either end at the following positions:

Position 1	0° — 180°
Position 2	45° — 225°
Position 3	90° — 270°
Position 4	135° — 315°

Length — Measured at center of ends of capsule.

Total-indicated-runout — The axial total-indicated-runout (TIR) shall be measured at positions of 0°, 90°, 180°, and 270° from end to end.

Parallelism — The degree of parallelism of the top and bottom shall be recorded.

Perpendicularity — The degree of perpencidularity of the axis of the capsule with the ends shall be recorded.

097209

Dimensional Measurements Data

Isotope Kilowatt Program Fuel Capsule

Sheet No. 1 Capsule Identification No. 1

Test Title _____

Pre-test _____ Post-test _____

RADIAL

Position	Actual (in.) 1 in. from Top	Middle	1 in. from Bottom	Design (in.)
1	4.1011	4.1009	4.0989	4.100 ± 0.002
2	4.1011	4.1010	4.0989	
3	4.1011	4.1010	4.0995	
4	4.1008	4.1011	4.0990	

LENGTH

Actual 40.290 in. Design 40.280 ± 0.005 in.

TOTAL-INDICATED-RUNOUT

Position	Actual (in.)	Design (in.)
0°	.001	±0.003 - Ref. To O.D.
90°	.001	
180°	.001	
270°	.001	

PARALLELISM

Actual .002 in. Design ±0.005 in.

PERPENDICULARITY

Actual To P. .0008" Bot. .002 in. Design ±0.005 in.

UCN-6810
(23 5-68)

UNION CARBIDE CORPORATION - NUCLEAR DIVISION

INSPECTION CERTIFICATION FORM

097209

Q. A. LEVEL No. III

☒ ORNL ☐ Y-12 PLANT

WORK ORDER/WORK REQUEST	SHOP ORDER/PROCESS NO	DRAWING	ITEM
G1058E-A3	IS-296	GPD-2773-C-R, Capsule Body-Part-3	Fuel Capsule

DISPOSITION	DATE	INSPECTOR	MAT'L HEAT OR LOT NUMBER
F.L.C. Hawley	SEP 14 1972	P.V. Stallo	Hastelloy-C-27

DIM NO.	SPECIFICATION	INSPECTION RESULTS Pc. No.	Pc. No.	Pc. No.	Pc. No.	Pc. No	Pc. No.
1	Temp. 65°-75°	W/IN TOL.					
2	Break Sharp Edges	Burr on .720 I.D. *					
3	Finish not To Exceed 32	35 L.D. *					
4	40.280"	40.290 *					
5	4.100 ±.002" Dia.	4.098 4.1011					
6	3.800" .005" max. clearance	3.799					
7	3 3/4"-8-Thread	W/IN TOL.					
8	1.062"	1.0765 +					
9	1/4"	W/IN TOL.					
10	1/8" Undercut To Root of Thd.	W/IN TOL.					
11	3.450" I.D.	3.454 3.4335 *					
12	.005" Max. R.	W/IN TOL.					
13	3.540" +.003" -.000"	3.545 +					
14	.006" Out of Round Tol.	.001"	The O.D. was the Ref. for out of Round				
15	⊙ To I.D. Within .003	.010 +					
16	Face ∥ within .005"	.002					
17	.720"	Heavy Burr .717					

Waived By _____ Date _____

UCN-6810
(23 5-68)

UNION CARBIDE CORPORATION - NUCLEAR DIVISION

INSPECTION CERTIFICATION FORM 097209

Q. A. LEVEL NO. III

☒ ORNL ☐ Y-12 PLANT

WORK ORDER/WORK REQUEST	SHOP ORDER/PROCESS NO.	DRAWING	ITEM
G1058E-A3	IS-296	CRD-2773-C-R, Capsule	Bottom Cap - Part - Fuel

DISPOSITION	DATE	INSPECTOR	MAT'L HEAT OR I R NUMBER
F.L.C. Hamley	SEP 14 1972	P.V. Stalla	Hastelloy-C-276

DIM NO.	SPECIFICATION	INSPECTION RESULTS Pc. No.	Pc. No.	Pc. No.	Pc. No.	Pc. No.	Pc. No.
1	Temp. 65°-75°F	W/IN TOL					
2	Break Sharp Edges	W/IN TOL					
3	Finish Not To Exceed 32	W/IN TOL					
4	3.539" +.000" -.002" Dia	3.538					
5	3.300" Dia	3.301					
6	.720"	~~.717~~ .718					
7	.780	.784					

Waived By _____ Date _____

CN-6810
(3 5-68)

UNION CARBIDE CORPORATION - NUCLEAR DIVISION

INSPECTION CERTIFICATION FORM

Q. A. LEVEL NO. III

☒ ORNL [ ] Y-12 PLANT

097209

Top Cap - Part - 1

WORK ORDER/WORK REQUEST	SHOP ORDER/PROCESS NO.	DRAWING	ITEM
G-1058E-A3	IS-296	CRD-2773-C-R1	Fuel Capsule

DISPOSITION	DATE	INSPECTOR	MAT'L HEAT OR LOT NUMBER
J.C. Hawley	SEP 14 1972	P.V. Stallo	Hastelloy-C-276

ITEM NO.	SPECIFICATION	INSPECTION RESULTS Pc. No.	Pc. No.	Pc. No.	Pc. No.	Pc. No.	Pc. No.
1	Temp. 65°-75°F	W/IN TOL.					
2	Break Sharp Edges	W/IN TOL.					
3	Finish Shall Not Exceed 132	W/IN TOL.					
4	3.795 "Fuel" - 000" Dia	3.7958					
5	3.300" Dia.	3.300					
6	2.750"	2.751					
7	1.375"	1.3755					
8	#7 Drill	W/IN TOL.					
9	5/16" Deep	W/IN TOL.					
10	Tap 1/4"-20-N.C.	W/IN TOL.					
11	1/4" Deep	W/IN TOL.					
12	1.060"	1.069					
13	1.00"	1.005 1.0096					
14	1/4"	W/IN TOL.					
15	1/8" Undercut To Root of Thread	W/IN TOL.					
16	3/4"-8-Thread	W/IN TOL.					

Waived By _____ Date _____

Page # 4

Dimensional Measurements Data

Isotope Kilowatt Program Fuel Capsule

Sheet No. 1 Capsule Identification No. II

Test Title Isotope Kilowatt Program Fuel Capsule

Pre-test _____ Post-test _____

RADIAL

Position	Actual (in.) 1 in. from Top	Middle	1 in. from Bottom	Design (in.)
1	4.1012	4.101	4.1012	4.100 ± 0.002
2	4.0995	4.101	4.0009	
3	4.100	4.101	4.1014	
4	4.0996	4.101	4.101	

LENGTH

Actual 40.278 in. Design 40.280 ± 0.005 in.

TOTAL-INDICATED-RUNOUT

Position	Actual (in.)	Design (in.)
0°	0	±0.003
90°	+.00125	
180°	-.0005	
270°	0	

PARALLELISM

Actual .003 in. Design ±0.005 in.

PERPENDICULARITY

Actual .001 .003 in. Design ±0.005 in.

UCN-68'0
(23 5-68)

UNION CARBIDE CORPORATION - NUCLEAR DIVISION

INSPECTION CERTIFICATION FORM

Q. A. LEVEL III

☑ ORNL ☐ Y-12 PLANT

59 Conforming
1 Non Conforming

097209

Page # 1

WORK ORDER/WORK REQUEST	SHOP ORDER/PROCESS NO	DRAWING	ITEM
G-1058 E A-3	15 296	CRD2773 C Rev-1	#1

DISPOSITION	DATE	INSPECTOR	MAT'L HEAT OR I.R. NUMBER
FIC HAMLEY	9-26-72	M. M. Hansen	

DIM NO.	SPECIFICATION	INSPECTION RESULTS Pc. No. 1	Pc. No.	Pc. No.	Pc. No.	Pc. No.	Pc. No.
1-	65° - 75° F	W/IN TOL.					
2-	Break Edges	W/IN TOL.					
3	Hastelloy C-276	W/IN TOL.					
	32	W/IN TOL.					
4-	3.795 +.001 -.000 DIA	3.795					
5-	3.300 DIA	3.2985					
6-	2.750 B.C.	2.750					
7-	1.375	1.375					
8-	#7 Drill	W/IN TOL					
9-	5/16" Deep	W/IN TOL.					
10.	Tap 1/4"-20 NC	W/IN TOL					
11.	1/4" Deep	W/IN TOL					
12.	1.060	1.060					
13.	1.000	1.000					
14-	1/4"	W/IN TOL					
15	1/8" Undercut	W/IN TOL.					
16-	3 3/4-8Thd.	W/IN TOL.					

Waived By _____ Date _____

CN-6810
(3 5-68)

UNION CARBIDE CORPORATION - NUCLEAR DIVISION

INSPECTION CERTIFICATION FORM

Q. A. LEVEL NO. III

☑ ORNL ☐ Y-12 PLANT

097209

Page #2

WORK ORDER/WORK REQUEST	SHOP ORDER/PROCESS NO	DRAWING	ITEM
G 1658E-A3	15-296		#2

DISPOSITION	DATE	INSPECTOR	MAT'L HEAT OR I.R. NUMBER
FIC Hamley	9-26-72	M. M. Hewes	

ITEM NO.	SPECIFICATION	INSPECTION RESULTS Pc. No. 2	Pc. No.	Pc. No.	Pc. No.	Pc. No.	Pc. No.
1.	65°-75° F	W/IN TOL					
2.	Break Edges	W/IN TOL.					
3.	MATL. Hastelloy C-276	W/IN TOL.					
	32	W/IN TOL					
4.	3.539 +.000 -.002 DIA	3.539					
5.	3.300 DIA	3.304					
6.	.720	.720					
7.	.780	.780					

Waived By _____ Date _____

JCN-6810
23 5-68)

UNION CARBIDE CORPORATION - NUCLEAR DIVISION

INSPECTION CERTIFICATION FORM

Q. A. LEVEL NO. III

☑ ORNL ☐ Y-12 PLANT

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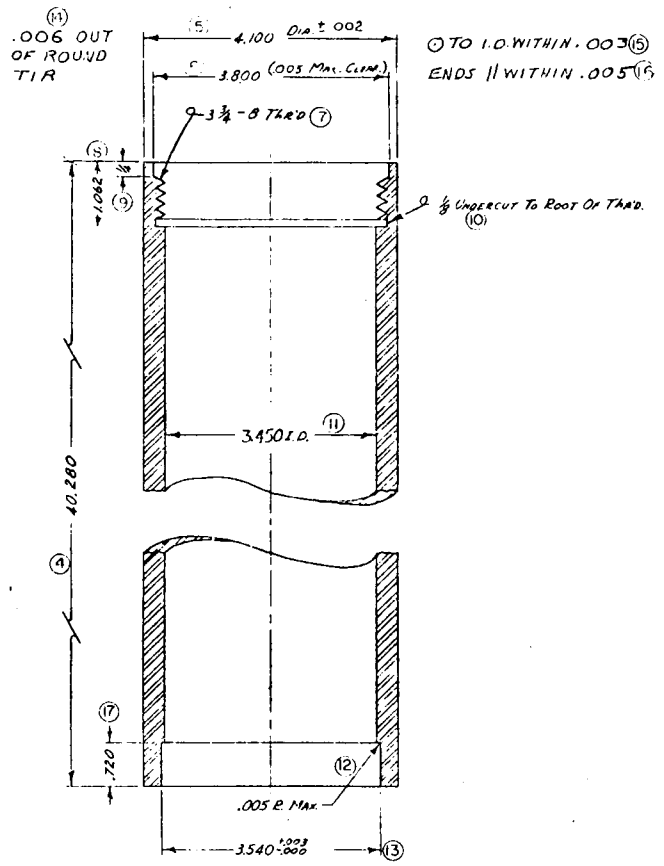
Page # 3

WORK ORDER/WORK REQUEST	SHOP ORDER/PROCESS NO.	DRAWING	ITEM
G-1058 EA3	15 296	CRD 2773C Rev 1	III

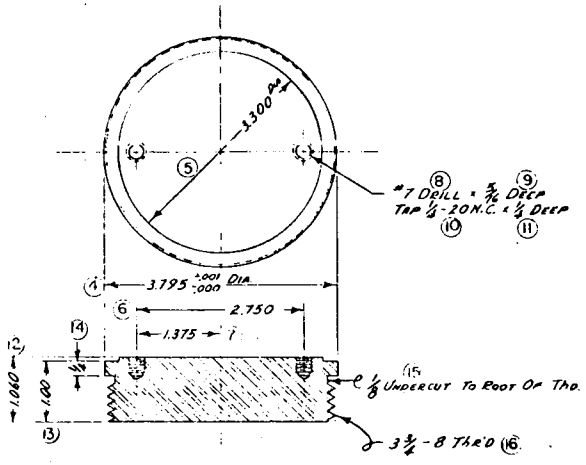
DISPOSITION	DATE	INSPECTOR	MAT'L HEAT OR I.R. NUMBER
Fic Hazley	9-26-72	W. M. Houser	

DIM NO.	SPECIFICATION	INSPECTION RESULTS Pc. No.	Pc. No.	Pc. No.	Pc. No.	Pc. No.	Pc. No.
1-	65° -75°	W/IN TOL.					
2-	Break Edges	W/IN TOL.					
3-	Hastelloy C-276	W/IN TOL.					
4-	132	165 *	inside	walls			
5-	4.100 +.002 -.000 DIA	4.100					
6-	3.800	3.800					
7-	3 3/4"-8 Thd	W/IN TOL.					
8-	1.062	1.063					
9-	1/4"	W/IN TOL.					
10-	1/8" undercut	W/IN TOL.					
11-	3.450 ID	3.448 Top End ~~3.5075 * Bottom End~~	Recheck = 3.4445 PKS				
12-	.005 Radius	.005					
13-	3.540 +.003 -.000	3.540					
14-	.003 TIR.	.001					
15-	To ID -.003	.001 / .003					
16-	Ends -.005	.001 / .003					

Waived By _____ Date _____

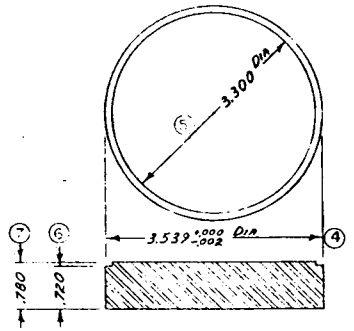


CAPSULE BODY
PART # 3



TOP CAP
PART #1

NOTES:
1. ALL MAT'L SHALL BE HASTELLOY C-276
(3) 2. FINISH ALL OVER 32
3. E.B WELD BOTTOM CAP - .120 DP. MIN.
4. PL. ARC WELD TOP CAP - .055 DP. MIN.



BOTTOM CAP
PART #2

(1) TEMPERATURE 65° - 75°F.
(2) BREAK SHARP EDGES UNLESS OTHERWISE SPECIFIED

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TOLERANCES UNLESS OTHERWISE SPECIFIED:						
FRACTIONS ± 1/64	NO.	REVISIONS			DATE	APPD	APPD
DECIMALS ± .005	DRAWN RHF	DATE 9-21-70	SUBMITTED	DATE	APPROVED	DATE
ANGLES ±	DESIGNED [illegible]	DATE 9-21-70	APPROVED	DATE	APPROVED	DATE
SCALE: 3/4" = 1"	CHECKED [illegible]	DATE [illegible]	APPROVED	DATE	APPROVED	DATE

REFERENCE DRAWINGS	NUMBER

OAK RIDGE NATIONAL LABORATORY
OPERATED BY
UNION CARBIDE CORPORATION
OAK RIDGE, TENNESSEE

BLDG. NO.

ISOTOPE KILOWATT PROGRAM
FUEL CAPSULE

SUBMITTED	ACCEPTED	APPROVED			
		CRD	2773	C	REV. 1

INTRA-LABORATORY CORRESPONDENCE

OAK RIDGE NATIONAL LABORATORY

February 22, 1973

To: K. W. Haff

cc: R. G. Donnelly
R. W. McClung
P. Patriarca
R. A. Robinson

Ultrasonic Inspection of Bottom Cap-to-Capsule Weldments on Isotope Kilowatt Program (IKP) Capsules

A standard containing 0.070-, 0.030-, and 0.015-in.-diam flat-bottom holes was fabricated in a weld test ring of the same material as the capsules and used to calibrate the ultrasonic inspection system. Commercial ultrasonic instrumentation (an Immerscope Model 725) using a 15-MHZ PZT transducer and the receiver detuned to 5 MHZ resulted in good sensitivity to the reference holes. Figure 1 is a typical plan view recording showing the response to the reference holes.

A dial gauge with a 2-in. movement was purchased and used to monitor the step position (the position at the inside corner of the cap) and subsequent transducer movement vertically along the capsule axis. A special electronic scanning amplifier system and various mechanical fixtures were required to perform the inspection on our laboratory scanner. The final inspection system was used to test a number of weld test rings to develop the inspection procedure. One test ring (No. 8) was sectioned in two places and the predicted values of maximum and minimum weld penetration agreed with measured values within ± 0.010 in. (minimum penetration was 0.150 in.).

Figures 2 and 3 are copies of the original inspection results obtained on capsule No. 1. Figures 4 and 5 are the original results obtained on capsule No. 2. The maximum penetration on the capsules was approximately 0.428 in. (capsule No. 1) and 0.360 in. (capsule No. 2). Capsule No. 1 meets the requirements listed in pages 26 and 27 of ORNL-TM-3230 (Isotope Kilowatt Program Fueled Capsule Design and Evaluation - A Safety Analysis by K. W. Haff). Capsule No. 2 has a number of smaller indications; however, the most significant one is near the capsule top corner (actually, the capsule bottom) and is labeled with an A. This indication breaks 14 lines of the x-y scan; whereas the 0.030-in. reference hole breaks 11 lines. Thus, indication A, by extrapolation, may encroach upon 0.040 in. in length and is marginally acceptable. Due to the facts that this indication is only borderline and the maximum penetration is about three times that required, the capsule was considered acceptable for further testing.

K. V. Cook

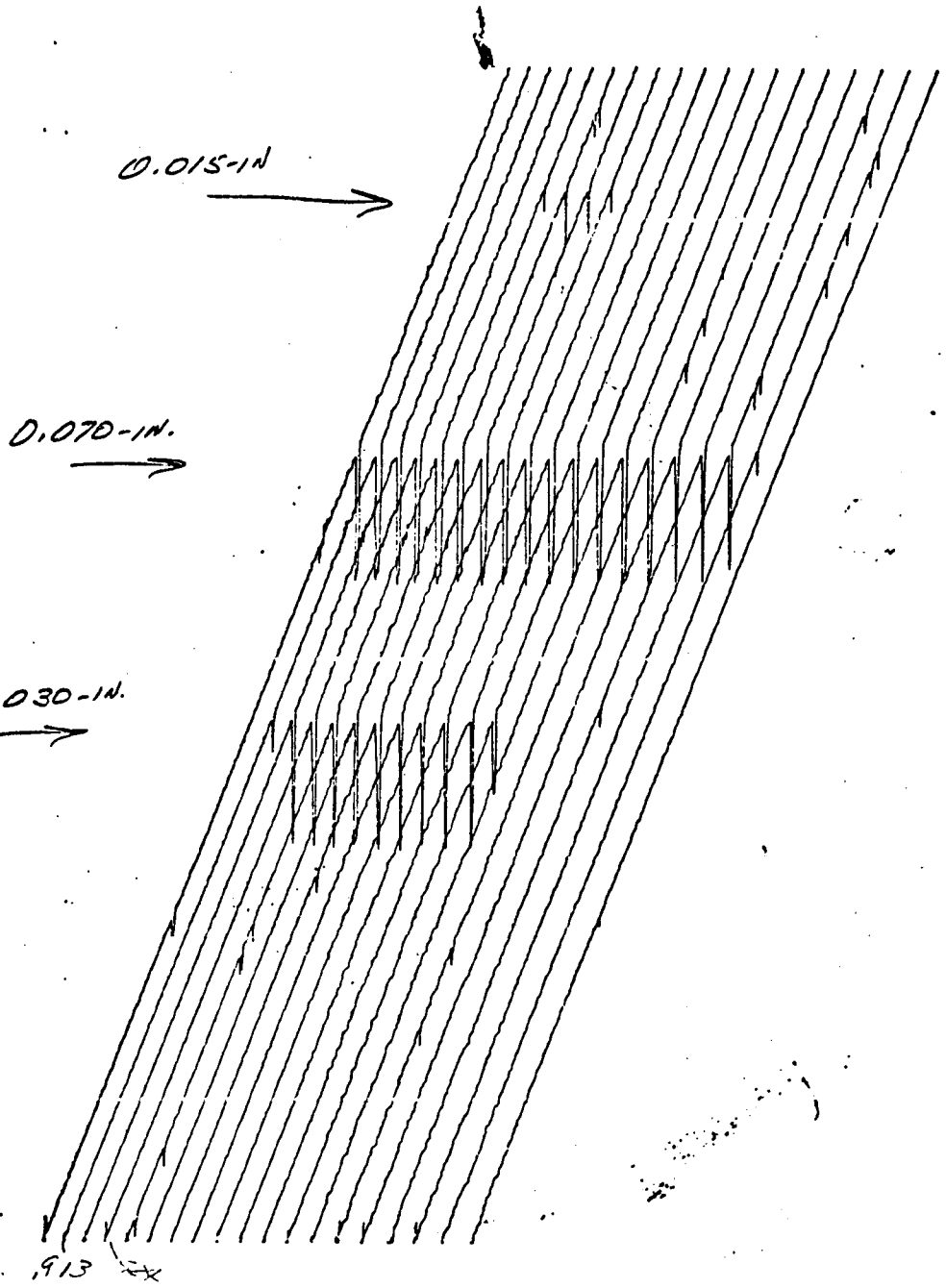
K. V. Cook
Metals and Ceramics Division

KVC:fc

UCN-430
(3 6-61)

Dec. 20, 72
1Kp Std
after Capsule #2
Irradiation

FIG #1



DEC 19 1972
IKP CAP. #1
TOP END
SCAN UP

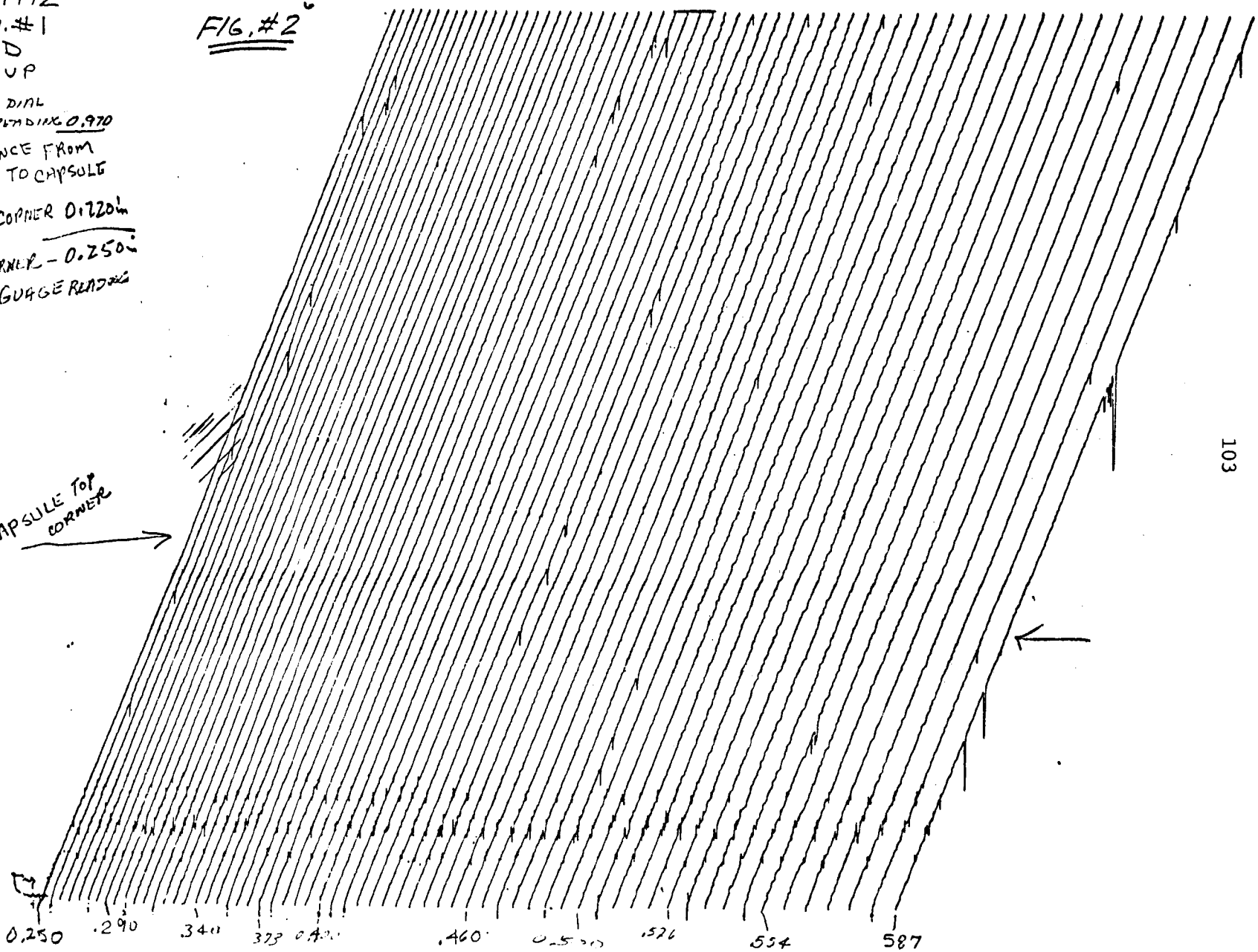
STEP AT DIAL GAGE READING 0.970

DISTANCE FROM STEP TO CAPSULE

TOP CORNER 0.1220in

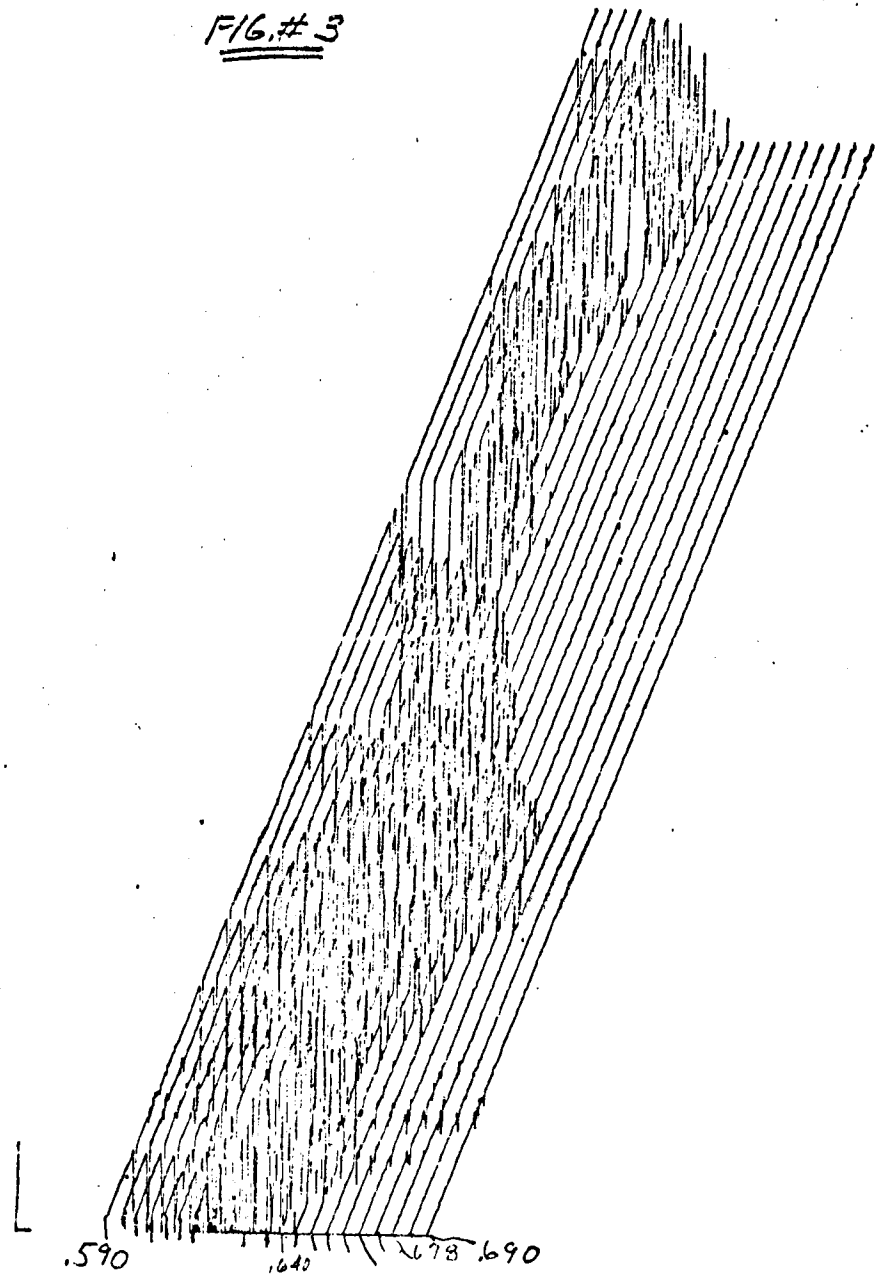
TOP CORNER - 0.250in
DIAL GUAGE READING

FIG. #2



DEC. 19, 72
IKP CAPS. #1
CONT'D

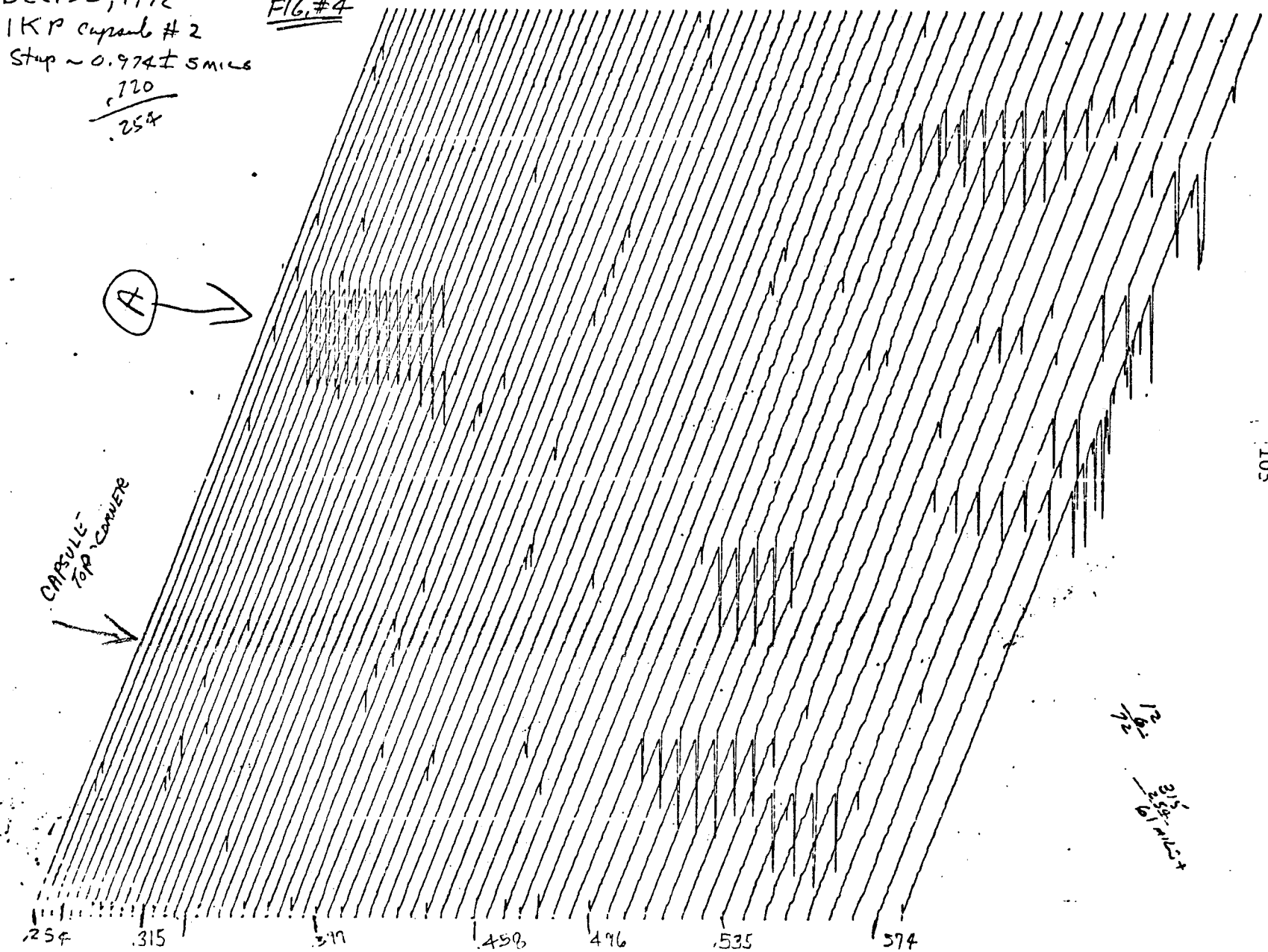
FIG. # 3



678 - 8.19 LG.
250 - TOP CONTOUR
0.428 MILS MAX. PENETRATION

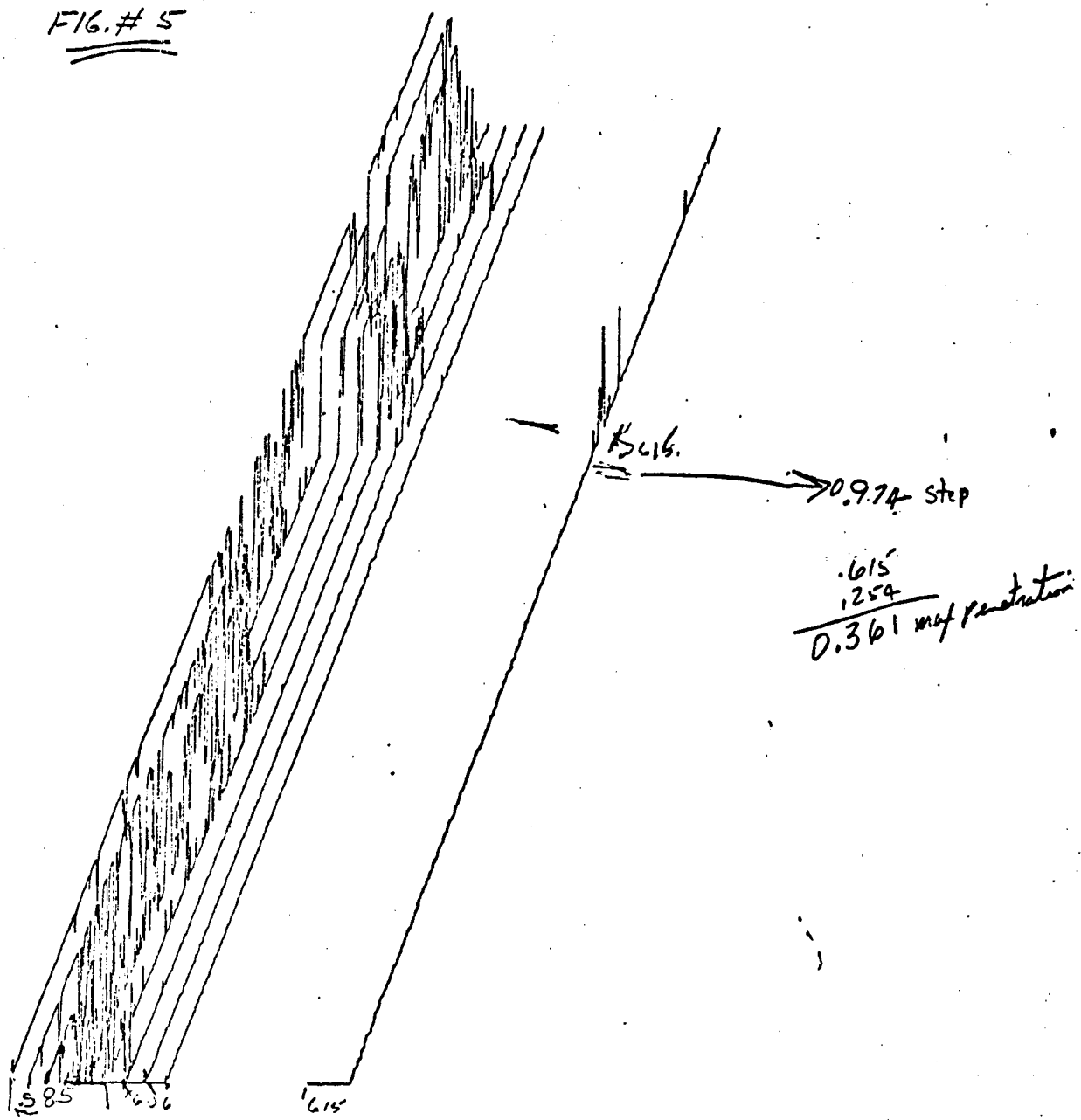
DEC. 20, 1972
IKP capsule #2
Step ~ 0.974 ± 5 mils
.720
.254

FIG. #4



Dec. 20, 1972
1Kp cap. #2 cont'd

FIG. # 5



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