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Vol. 4

Sealed Source and Device Design Safety Testing

Technical Report on the Findings of Task 4

Investigation of Sealed Source for Paper Mill Digester

Prepared by
D. J. Benac, F. A. Iddings

Southwest Research Institute

Prepared for
U.S. Nuclear Regulatory Commission

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Abstract

This report covers the Task 4 activities for the Sealed Source and Device Safety testing program. SwRI was contracted to investigate a suspected leaking radioactive source that was installed in a gauge that was on a paper mill digester. The actual source that was leaking was not available, therefore, SwRI examined another source. SwRI concluded that the encapsulated source examined by SwRI was not leaking. However, the presence of Cs-137 on the interior and exterior of the outer encapsulation and handling tube suggests that contamination probably occurred when the source was first manufactured, then installed in the handling tube.

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Acknowledgements

Special acknowledgements are warranted for the following individuals at Southwest Research Institute (SwRI) for their contribution to the Investigation of the Encapsulated Sealed Source.

Mr. Frank Iddings and Mr. Ty Schraeder for advice on radiation safety control, handling of the sources, and cutting the outer encapsulation.

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Ms. Rachel Muñoz for her clerical support.

Sealed Source and Device Safety Testing

Technical Report on the Findings of Task 4

Executive Summary

This report addresses an incident which occurred at Rosemount (Kay-Ray/Sensall) where it was suspected that a General Radioisotopes Product (GRP) source was leaking radioactive material. The source was installed in a gauge that was originally installed on a paper mill digester. The digester contains acid used to break down wood in the process of making paper. The GRP sealed source model 6082, S/N 624, contained Cesium-137 (approximately 1.6 curies). The source, with its source holder, had been removed from a Kay-Ray/Sensall Model 7063, specifically licensed gauge by Rosemount personnel.

The state of Illinois requested the NRC conduct a failure analysis of the GRP sealed source (S/N 624) from the Georgia facility. The source, S/N 624, that was suspected leaking was not examined because it was damaged during removal from its source holder. Furthermore, the disposal container in which the source was placed was contaminated by the leaking source. The source was suspected as leaking after a wipe test was performed at Kay-Ray/Sensall. However, it could not be determined if the source was leaking because it was severely damaged during removal from its source holder. This damage caused release of the contained Cs-137 and widespread contamination (it was definitely leaking after the damage). An alternate source was selected because SwRI felt the chances of gaining useable information from the damaged source were minimal.

Based on the fact that the S/N of the source in storage at the Georgia facility is one serial number different (S/N 625) than the leaking source returned to Kay-Ray/Sensall, (S/N 624), and that the source was installed at the same time and exposed to the same environments, the NRC and the state of Illinois decided to use this alternate source for analysis to possibly determine a cause for leakage of S/N 624 and to identify possible leakage points for these sealed sources. The investigation determined the actual serial number of the source as S/N 626.

SwRI investigated the sealed source for the presence of any corrosion, or unusual physical or metallurgical feature which may contribute to leakage of radioactive material from the sealed source. SwRI visually examined the sealed source and performed wipe tests throughout the evaluation to determine evidence of contamination and leakage. The source outer encapsulation was sectioned to examine the weld quality and look for possible cracks and to allow examination of the inner capsule.

Based on these evaluations, it was concluded that the encapsulated source (S/N 626) examined by SwRI was not leaking. However, the presence of Cs-137 on the interior and exterior of the outer encapsulation and handling tube suggests that contamination probably occurred when the source was first manufactured, then installed in the handling tube.

Consequently, the actual cause for leakage of source S/N 624 was not determined. It is feasible, that leakage may have occurred due to a stress corrosion cracking mechanism, but this would require verification through analysis of the actual source (S/N 624). However, this source was subsequently disposed of by Rosemount/Kay-Ray.

1.0 Background

This report is provided in response to a request from the NRC, dated 29 April 1994. This request was issued based on an incident which occurred at Kay-Ray/Sensall where it was suspected that a source was leaking radioactive material. The source was originally installed on a paper mill digester as shown in Figure 1. The digester contains acid used to break down wood in the process of making paper. Furthermore, the gauge was exposed to the outside elements.

A summary of the events surrounding the incident, as reported to SwRI personnel by the staff at the NRC and Kay-Ray/Sensall, is as follows. The incident at Kay-Ray/Sensall involved a General Radioisotopes Product (GRP) sealed source model 6082, S/N 624, containing Cesium-137 (approximately 1.6 curies). The source, with its source holder, was removed from a Kay-Ray/Sensall Model 7063, specifically licensed gauge. It was suspected, from previous wipe tests, that the source was leaking (in the nanoCurie range), after it had been placed in a disposal container along with approximately 28 other Cesium-137 sources of various activity.

SwRI investigated the feasibility of acquiring the sealed source for analysis. It was determined that it would be necessary for SwRI to take receipt of the entire disposal container since it was possible that the source had contaminated the contents of the container. Also, SwRI learned that the source had been removed from its source holder using a mandrel, which could have damaged the source containment further. It was felt that the damage could compromise the ability of SwRI to determine the actual cause of the leakage. The composition of the disposal container was determined and a drawing showing that the source was doubly encapsulated was supplied by Kay-Ray/Sensall, see Figure 2.

Since SwRI could not report a high probability of determining the cause of the leakage from this possibly damaged source (S/N 624), and since SwRI would have to eventually dispose of a container housing numerous sources, the NRC decided (in conjunction with the Agreement State of Illinois), not to pursue the acquisition of the disposal container. Instead, (S/N 625) acquisition of a source, which was one serial number different from the leaking source identified, was pursued. This source was in storage and had seen service on Digester No. 1 at the same facility from which the leaking source had come.

According to the RSO at the Georgia facility, the gauge SwRI obtained was located in the most harsh atmosphere (even worse than the gauge in which the suspected leaking source was installed) in which these gauges are mounted at the plant. Huge tanks containing liquid caustic which are approximately 40 feet in diameter and 10-20 feet tall are located approximately 75 feet to the north of the location where the digesters and fixed gauges were located. Winds carry smelly, corrosive atmosphere to the fixed gauge locations. The digesters to which the gauges are mounted are approximately four stories tall. The fixed gauges are protected from some overhead and side precipitation by a metal shield ("birdhouse") fashioned over the top and sides of the fixed gauge housing, see Figure 1. These "birdhouses" were installed approximated two years ago. The received gauge has a service history closely matching that of the gauge containing the suspected leaking source.

The gauge was placed in service approximately January 28, 1977 and was placed into storage December of 1993.

In an effort to gather further information on the source design, SwRI attempted to contact the manufacturer of the source. It was learned from the licensing personnel at the Agreement State of California, that the company is out of business.

Based on the fact that the source in storage at the Georgia facility was indicated to be one serial number different (S/N 625) than the leaking source returned to Kay-Ray/Sensall (and similar history), the NRC and the state of Illinois decided to use this particular source for analysis to attempt to determine a cause for leakage and identify leakage points for the sealed source (S/N 624).

2.0 Scope of Work

A failure analysis of a single GRP sealed source from the Georgia facility was conducted. The presence of any corrosion or unusual physical or metallurgical feature which may contribute to leakage of radioactive material from a sealed source was sought. Specific activities performed during the failure analysis included the following.

- SwRI coordinated with the Georgia facility to ensure that the source was received within its source holder. This minimized the chance of the source receiving any damage which might impair SwRI's analysis of potential cause and location of source leakage.

- The history (age, operating and storage environments) of the source was pursued.

- Upon receipt at SwRI and throughout the evaluation, an inspection of the source, within its holder, was made. Radioactive contamination was removed from the resulting specimens using a wipe to allow an examination using a Model RM-14 frisker for measurement of contamination.

- The double encapsulated source was visually inspected to determine if any evidence of corrosion or unusual physical feature was on the surface. This was accomplished using optical techniques.

- Since a cause of potential contamination and location was not adequately determined from a visual examination, the source was cut through its midsection so that only the outer capsule was breached. The welds and the interior of the outer capsule were inspected for signs of corrosion and cracks.

- A visual and radiation level check was performed on the inner capsule. The inner capsule was not sectioned since SwRI felt no further information would be gained by sectioning the source and due to additional radiation safety concerns.

Several steps within the failure analysis required the use of the High Level Radiation Effects Facility operated under the direction of our Radiation Safety Officer, Dr. Frank Iddings. The failure investigation was conducted by Mr. Daniel J. Benac from SwRI's Materials and Failure Analysis Lab.

3.0 Evaluation of the Double Encapsulated Source

SwRI evaluated the possibility of a breached double encapsulated source using a deliberate evaluation. At each step, radiation levels were taken to assess if contamination was present. The steps for evaluation included characterizing the as-received condition of the source in the holder, the handling tube, the outer encapsulation (unsectioned, then as-cut) and the inner encapsulation unsectioned. A detailed description of the procedure and results follow. Table 3-1 is a summary of the radiation measurements.

Table 3-1. Radiation Levels of the Source Holder During Different Stages

Date	Location	Radiation Level
8/12/94	Beam End, Holder in Housing	65 mR/hr.
8/12/94	Side of Housing	10.8 mR/hr.
8/15/94	Wipe Under Plug	3,000 cpm (removable) 0.132 µcuries
9/8/94	Handling Tube Inside	500 cpm (removable) 0.018 µcuries
9/12/94	Sectioned Handling Tube	35,000 cpm (removable) 1.59 µcuries
9/27/94	Exposed Outer Capsule	2,000 cpm (removable) 0.087 µcuries
9/29/94	Exposed Outer Capsule	2,000 cpm (removable) 0.087 µcuries
10/6/94	As-Cut Outer Capsule (welded end) As-Cut Outer Capsule (non-welded end)	10,000 cpm (fixed) 0.452 µcuries 40,000 cpm (fixed) (1.82 µcuries)
12/6/94	Inner Capsule (before cleaned)	2,000 cpm (removable) 0.087 µcuries
12/6/94	Inner Capsule (after cleaned)	100 cpm (0.0046 µcuries)

The Housing and Source

When the Cs-137 source was received from Georgia facility at SwRI, it was examined in the box. The radiation was not above background. The shield was removed from the housing, then the lock for the housing was unlocked, then the aperture plug for the beam rolled back. Figure 3 shows the plug and the holder. The radiation level above the beam measured 65 mR/hr, on the side of the housing the radiation level measured 10.8 mR/hr. A wipe was taken underneath the aperture plug and a 3,000 cpm (0.132 μcuries) removable was detected. The area around the plug and down the beam hole was cleaned using Q-tips and cotton balls.

The Handling Tube

The three screws which fastened the source holder to the housing were removed, and then the holder was removed, see Figure 4. Figure 5 shows the as-received condition of the holder. The source end is shown in Figure 6. The wipes were taken down the source holder tube, using Q-tips. It was confirmed that the radiation X-rays were Cs-137, using gamma spectrometry. The instrument used was the Canberra Series 100 Multichannel Analyzer with a Ge detector.

It was reported to SwRI that the source holder was stainless steel or aluminum, but it was obvious based on the color and weight that the holder was an aluminum alloy. The OD measured 0.563 inch while the ID measured 0.438 inch. The holder tube was cut using a jewelers saw and hack saw, then split in half, as shown in Figure 7, exposing the double encapsulated source. The inside of the tube measured 40,000 cpm (1.82 μcuries).

The exposed double encapsulated source, shown in Figure 8, shows very slight corrosion and the weld region was darkened, likely due to heat input. There was no evidence of stains or obvious cracks since the stainless steel encapsulated source was unattacked. It is possible that some of the corrosion was transferred from the aluminum holder. When the source was exposed, it was noticed that the S/N on the source was stamped with the alpha-numeric SR626 Mar70. The test certificate received with the housing and source stated SR625.

The double encapsulated source was cleaned and the radiation level was 2,000 cpm (0.087 μcuries). The double encapsulated source was allowed to sit for 2 days, then rechecked. The wipe test revealed 2,000 cpm (0.087 μcuries) indicating no change. A helium leak test was performed by subjecting the encapsulated source to 100 psi of helium for 1 1/2-hour. Then, the encapsulated source was dumped into a bath of water. No bubbles formed indicating no helium leakage into the encapsulated source. Therefore, it is reasonable to believe that the outer encapsulation was not breached. This test satisfied the requirements of American National Standard N542, Sealed Radioactive Sources[1].

The Sectioned Outer Encapsulation

The next step was to section the outer encapsulation. Before this could be accomplished SwRI had to amend its radioactive material licenses to cut into a source. This amendment was allowed by the state of Texas. In order to cut the outer encapsulation without damaging the inner encapsulation, a special cutting fixture was set-up. The outer encapsulation was chucked into a variable speed drill set at a low rotational speed. The on-off switch was remote from the drill to minimize radiation exposure. The drill and chuck were covered with a plastic sheet and plate to catch the fillings. As the encapsulated source rotated, the source was cut with a jeweler's saw that was held by the manipulators. When the cut was completely through, the welded portion stopped rotating and could be removed. The non-welded half had 40,000 cpm (1.82 µcuries) on the outside, but only about 10,000 cpm (0.452 µcuries) on the inside. The welded and non-welded sections are shown in Figures 9 and 10. The inner capsule was only barely scratched from the cutting operations. No corrosion was evident on the inside capsule.

The top portion of the cap that had the weld was fluorescent dye penetrant and X-ray inspected. No indications of cracks were found. Figure 11 shows the radiograph of the weld.

Finally, the portion with the weld was sectioned in half to examine the quality of the weld. Figure 12 shows the welds had adequate fusion with no signs of cracking.

The Inner Encapsulation

The inner capsule was wipe tested. It was found that the radiation level was below typical background and was less than 100 cpm. The source was wiped with Q-tips after 24 hours and found to have no change in the radiation level. Figure 13 shows the condition of the inner capsule. Again, there were no signs of discoloration, corrosion, or cracking. To further evaluate if the capsule was cracked, a helium leak test was performed. Like before, the capsule was subjected to 100 psi of helium for 1 1/2-hour. Then, the encapsulation was dumped into a bath of water. No bubbles formed indicating no helium had migrated into the encapsulated source. Therefore, it is reasonable to believe the inner encapsulation was not cracked.

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[1] American National Standard N542 states that sealed sources which have an internal void volume greater than 0.01mL can be helium tested. The void content on the outer capsule was estimated to be greater than 0.15 mL. This is because of the recessed plug on the inner encapsulation. Therefore, the helium test is a valid method to evaluate if the outer encapsulation was breached. The inner capsule should have an even larger internal column because of the asbestos filled fiber nest.

The inner encapsulation was not sectioned. SwRI believed that no new information would add to the investigation and that radiation contamination would occur if the inner capsule was sectioned.

4.0 Summary and Discussion

The following observations were made as a result of examining the double encapsulated source.

1) Visual examination showed some evidence of external corrosion to the encapsulated source, but the corrosion was very minor.

2) Loose radioactive contamination was found on the double encapsulated source. Gamma spectrometry indicated the presence of Cs-137 at about 40,000 cpm (1.82 μcuries) on the outer capsule and handling tube.

3) Helium tests and metallographic sections gave no indication of cracks in the inner and outer encapsulation. The weld, heat affect zone, or base metal had no indications of cracks.

4) SwRI concluded that the specific source examined was not leaking.

This investigation was unable to determine a mechanism of failure for source S/N 624 because source S/N 626 that was examined was not leaking and the source showed no signs of potential mechanisms for leakage. A low level of contamination was found on the outer and inner encapsulation of the source, this was identified as Cs-137. Because the source was not leaking, the contamination had to come from an external source. Either the source was contaminated when manufactured or installed nearly 15 years ago or after it was removed and stored with other sources.

SwRI was unable to determine a cause for the suspected leakage in source S/N 624 from the evaluation of this nonleaking source S/N 626. However, because the encapsulated sources were fabricated from a stainless steel which is susceptible to stress corrosion cracking (SCC), SwRI proposes a possible scenario for consideration. The leakage may have resulted from either external or internal environmental SCC. SCC can readily occur in austenitic stainless steels that are exposed to a hostile environment, i.e., chlorides or caustic, while subjected to external or residual stresses.

The external corrosive environment would be the caustic tanks in the vicinity of the digesters. The tanks may have created a corrosive atmosphere that would condense in the tube holder for the source. This would expose the non-welded end of the encapsulation to the environment. The source, S/N 626, examined in this investigation did not have any build-up of corrosive material, however.

The other possible generator for environmental attack would be the Cs-137 source itself. Although the form of the Cs-137 was not confirmed by SwRI, it is believed that the source was cesium chloride pellets. Based on the age of the source, (15-17 years), cesium chloride pellets were considered the most likely form of Cs-137. The pellets could be a source of chlorides to cause corrosion and SCC.

A likely place for cracking to occur would be in the heat affected zones of the welds. In the HAZ, often high residual stresses and sensitization[2] can result in preferential attack. However, the encapsulated source, S/N 626, had good weld quality with good fusion and not a large HAZ. A sensitization etch on this weld indicated the HAZ was not sensitized.

Because SCC is often transgranular or intergranular it can be readily identified from other failure modes. For example, chloride stress corrosion cracking is typically composed of branched cracks which are easily distinguished in a metallurgical cross section. Consequently, it is possible to identify the SCC mechanism even if a source has been damaged by mechanical means.

In summary, no definitive evidence was found on the source, S/N 626, examined to explain leakage on source S/N 624. It is feasible that S/N 624 failed by a SCC phenomena. However, examination of the leaking source would be needed for verification. However, this was not possible since the source was disposed of by Rosemount/Kay-Ray.

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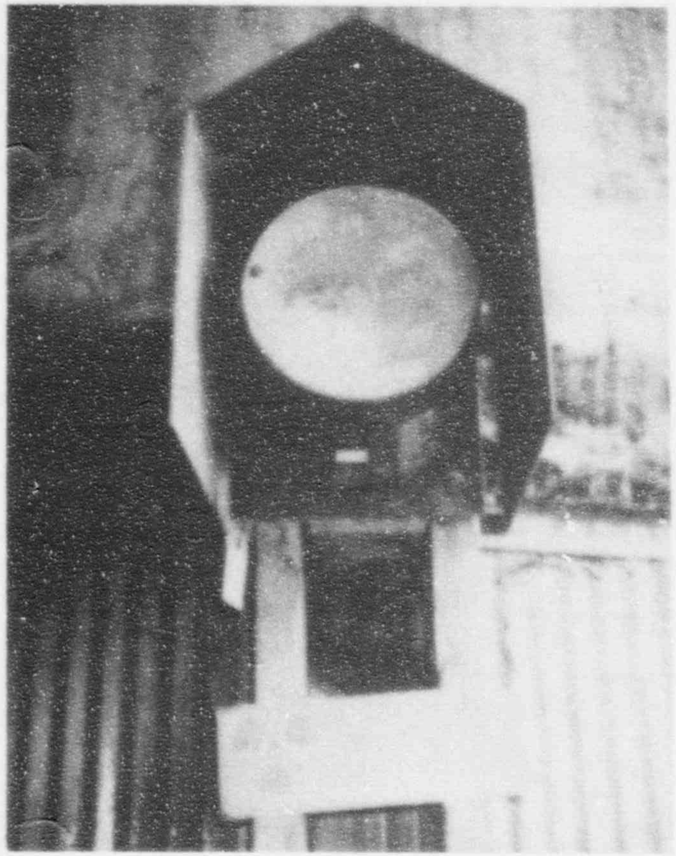
[2] Sensitization occurs in austenitic stainless steels that are heated or cooled slowly through a temperature range of 900 to 1400°F, eg; when welded. In this temperature range, chromium carbons precipitate in the grain boundaries resulting in depletion of chromium along the grain boundaries. The depletion of chromium in the grain boundaries can often result in preferential intergranular attack if a corrodent is present.



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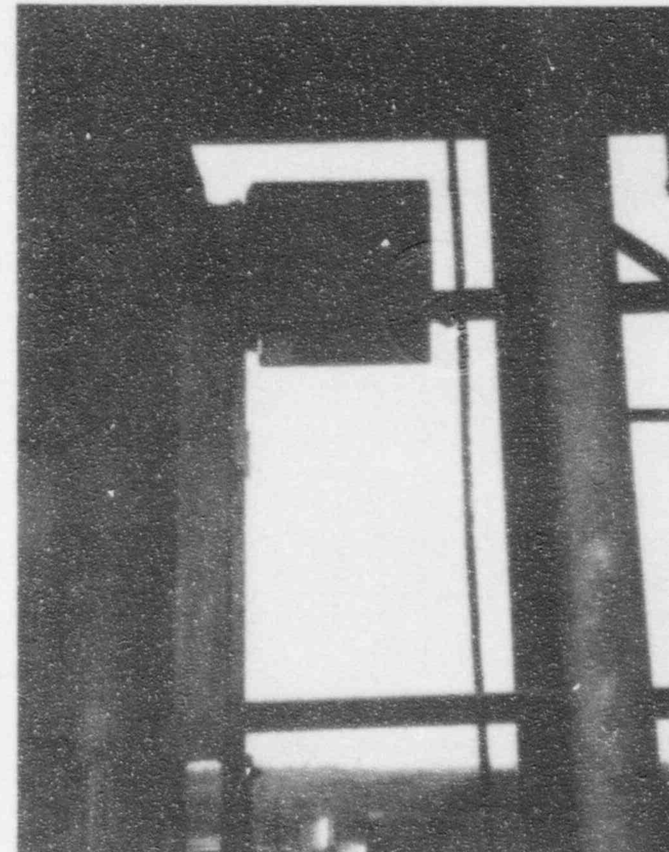
a)



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b)

FIGURE 1. PHOTOGRAPHS OF THE LOCATION OF THE HOUSING (a) ON THE DIGESTER.

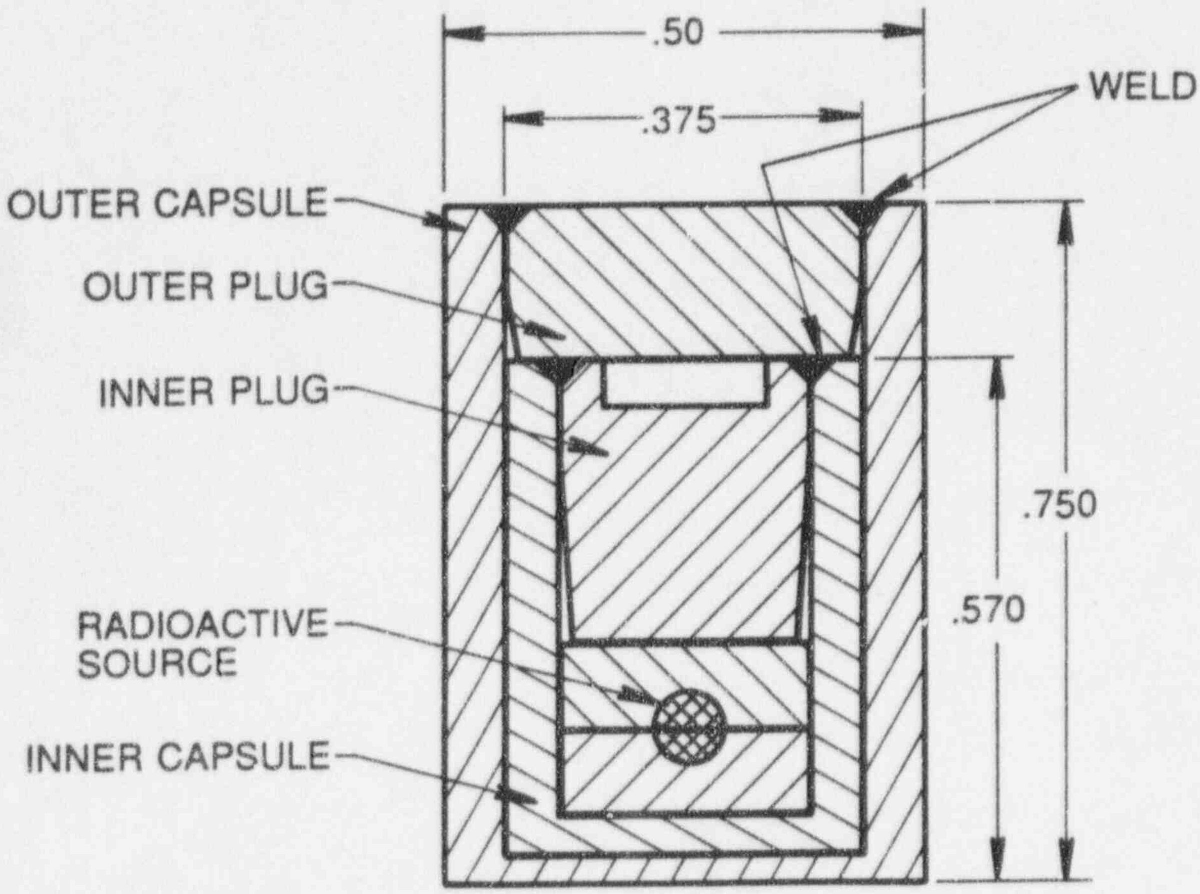


FIGURE 2. ILLUSTRATION OF THE ENCAPSULATED SOURCE.

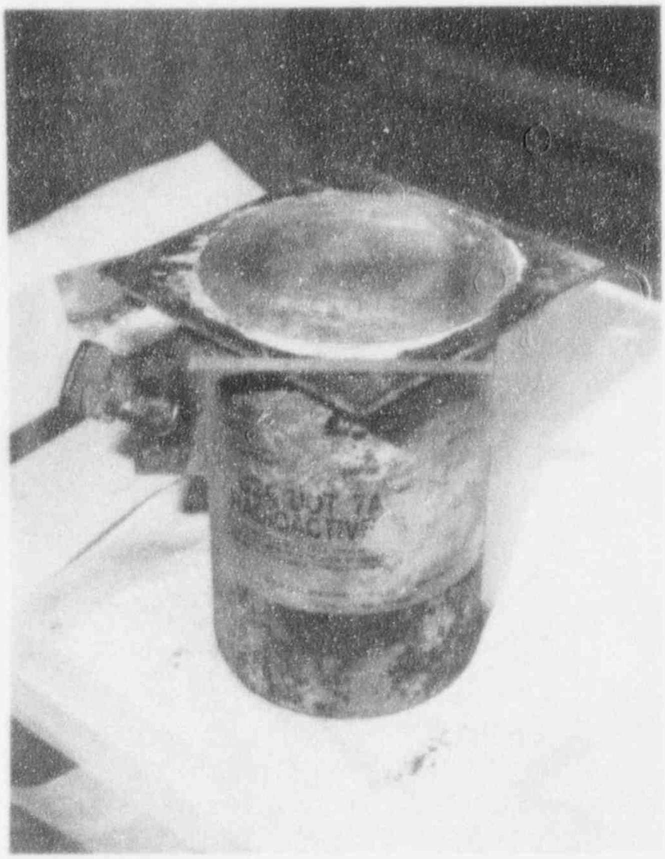
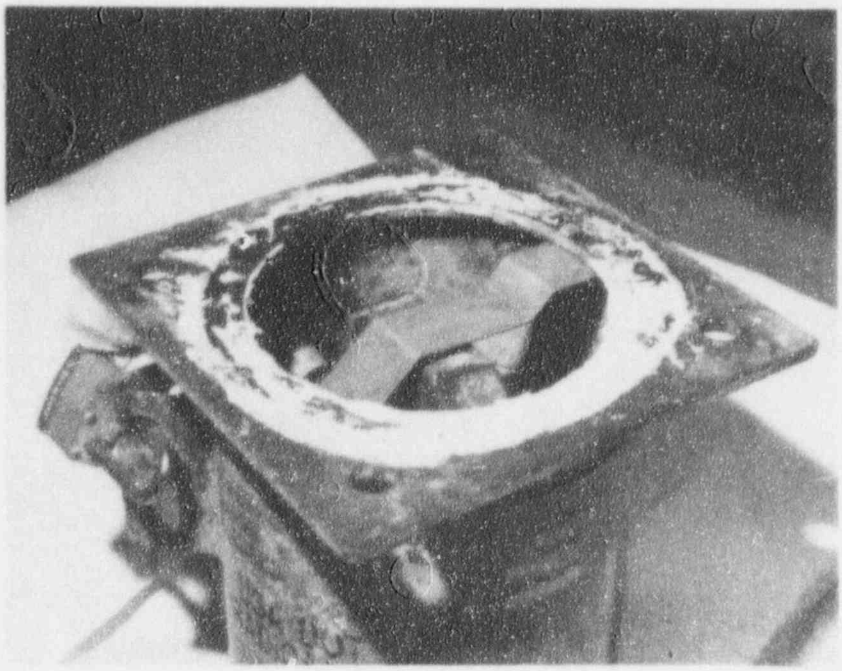


FIGURE 3. PHOTOGRAPHS OF THE HOUSING.



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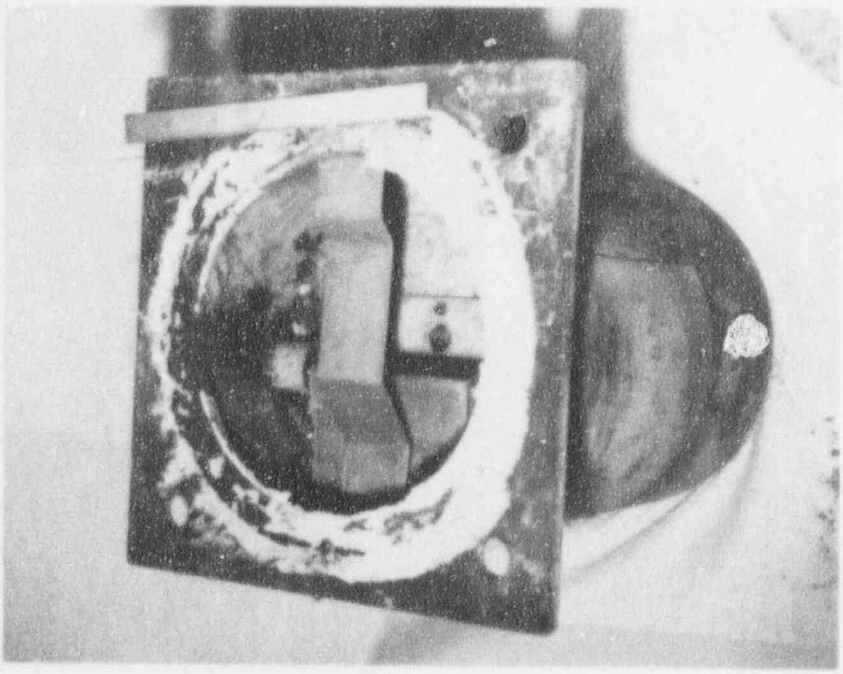
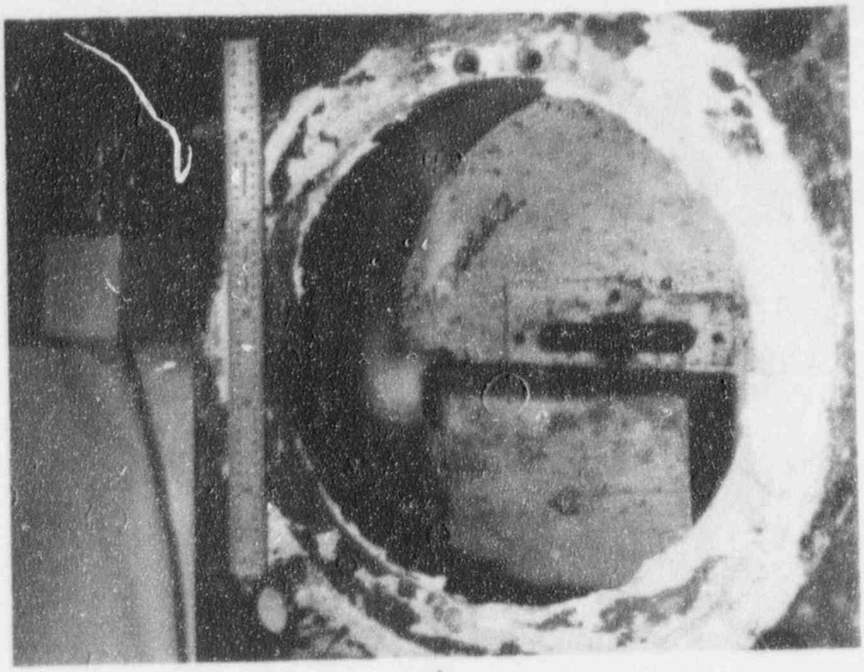


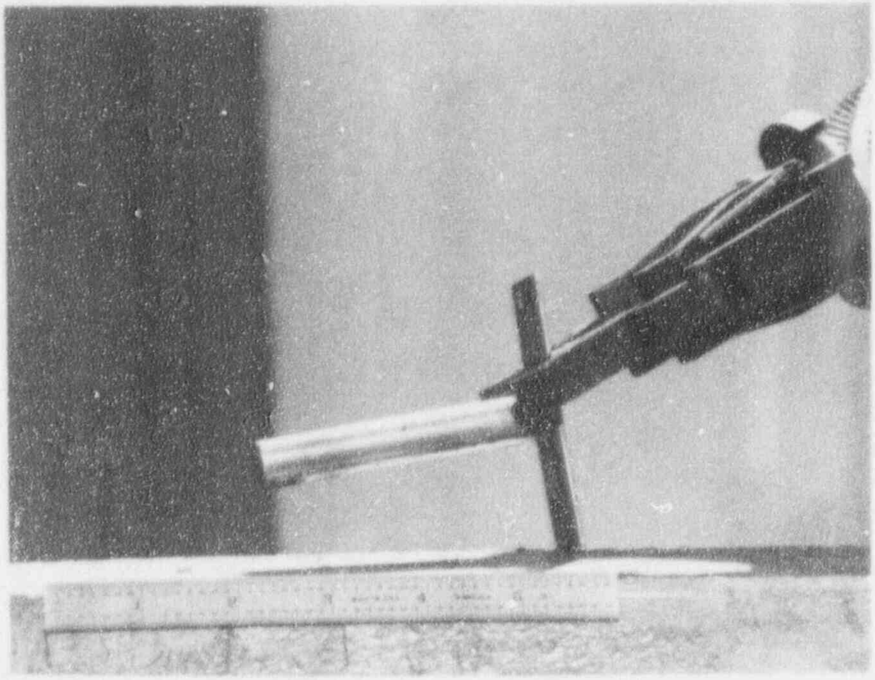
b)

FIGURE 4. PHOTOGRAPHS OF THE LEAD SHIELDING (a) THE HOLDER (b) AND THE HOLDER REMOVED (c).



c)

FIGURE 4 (continued). PHOTOGRAPHS OF THE LEAD SHIELDING (a) THE HOLDER (b) AND THE HOLDER REMOVED (c).



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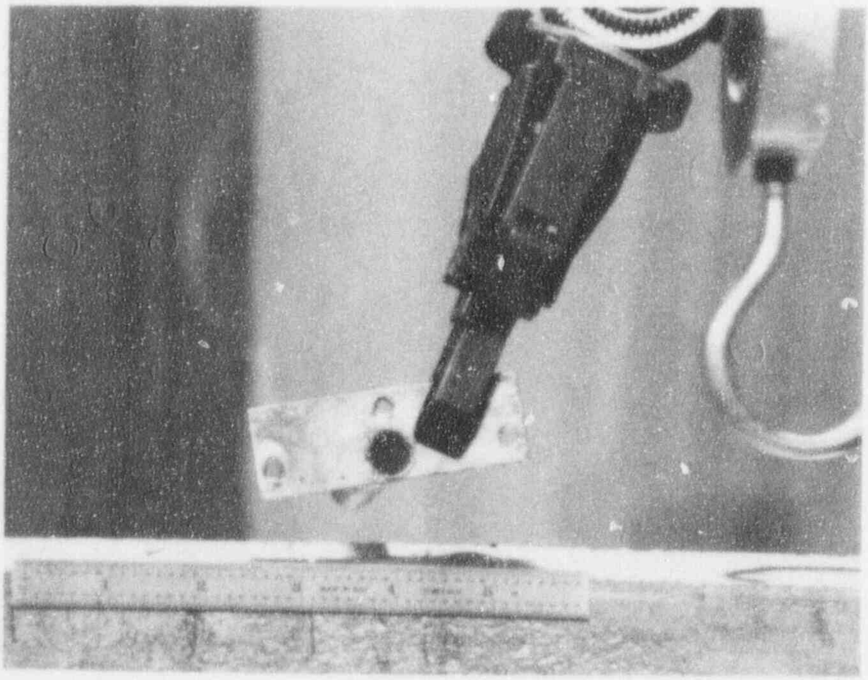
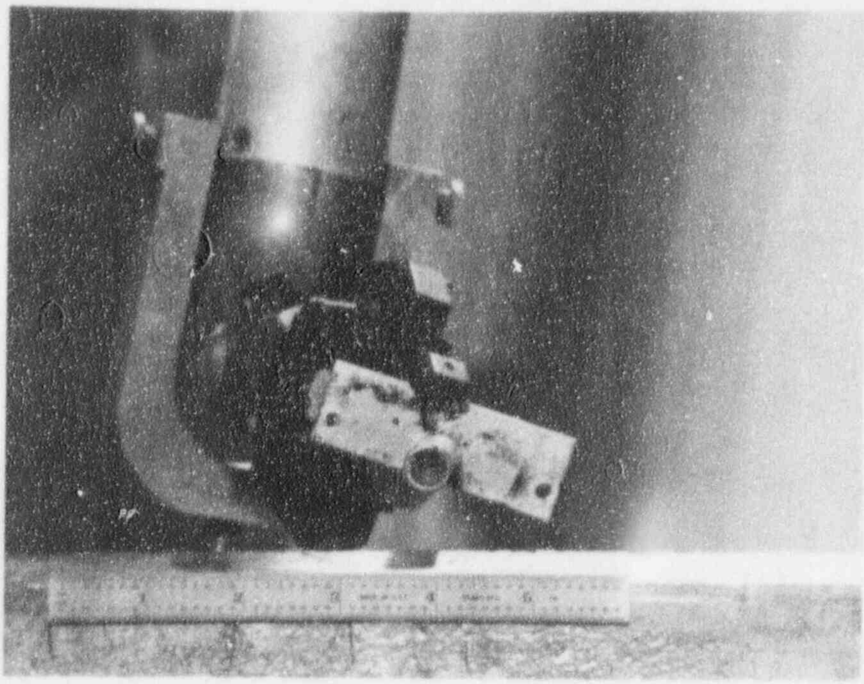


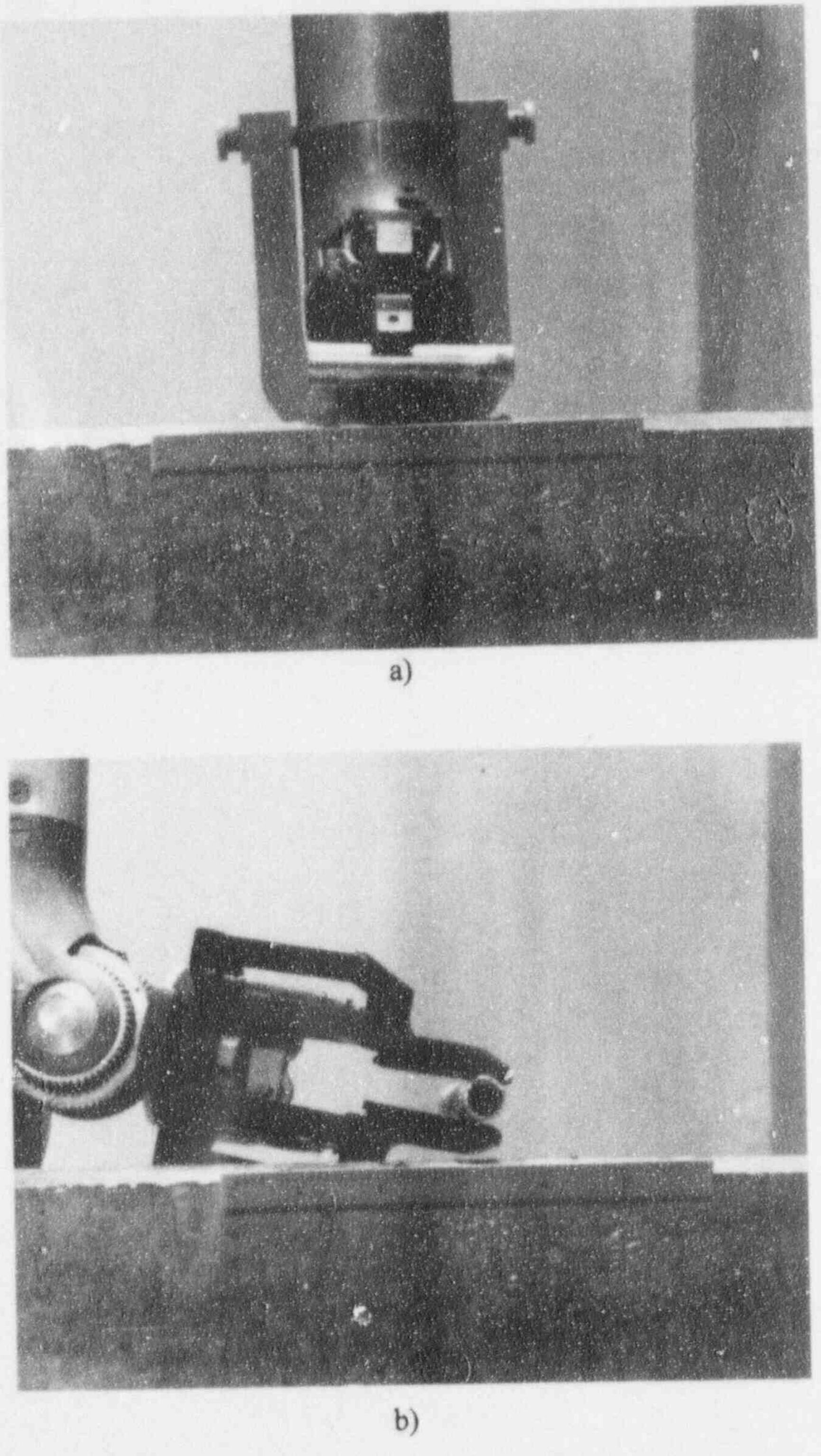
b)

FIGURE 5. PHOTOGRAPHS OF THE ALUMINUM HOLDER AND SOURCE.



c)

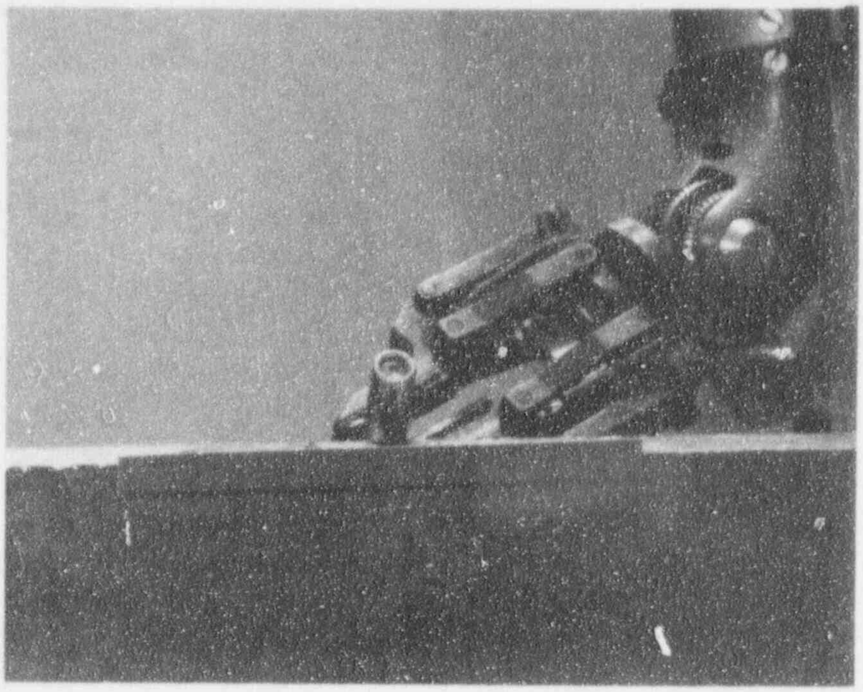
FIGURE 5 (continued). PHOTOGRAPHS OF THE ALUMINUM HOLDER AND SOURCE.



a)

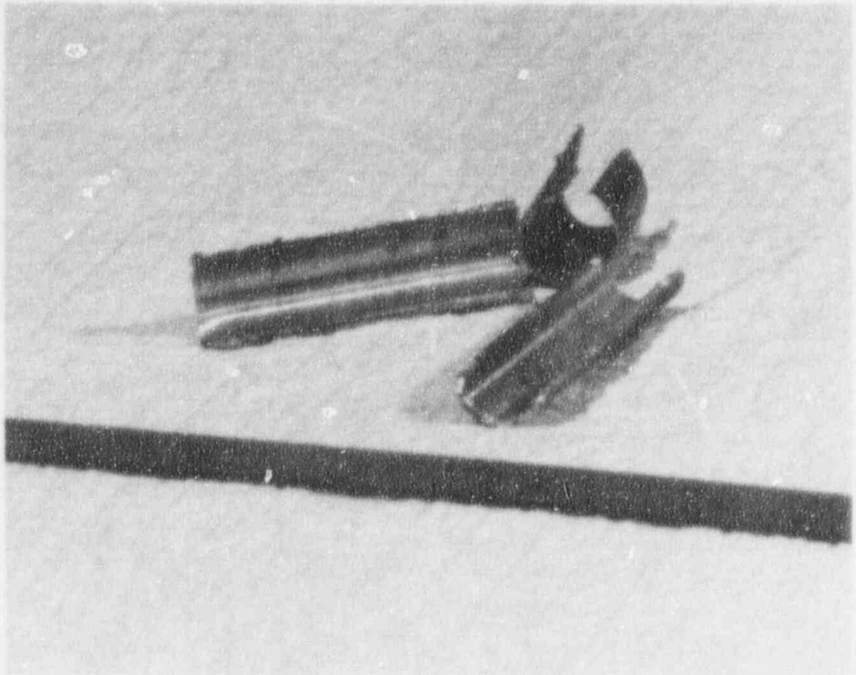
b)

FIGURE 6. PHOTOGRAPHS OF THE CUT HOLDER.



c)

FIGURE 6 (continued). PHOTOGRAPHS OF THE CUT HOLDER.



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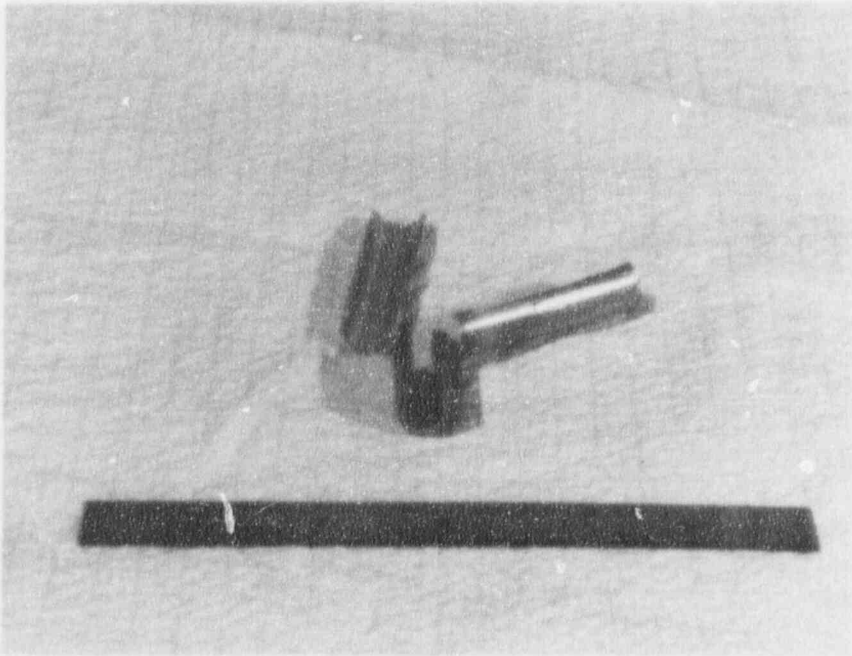
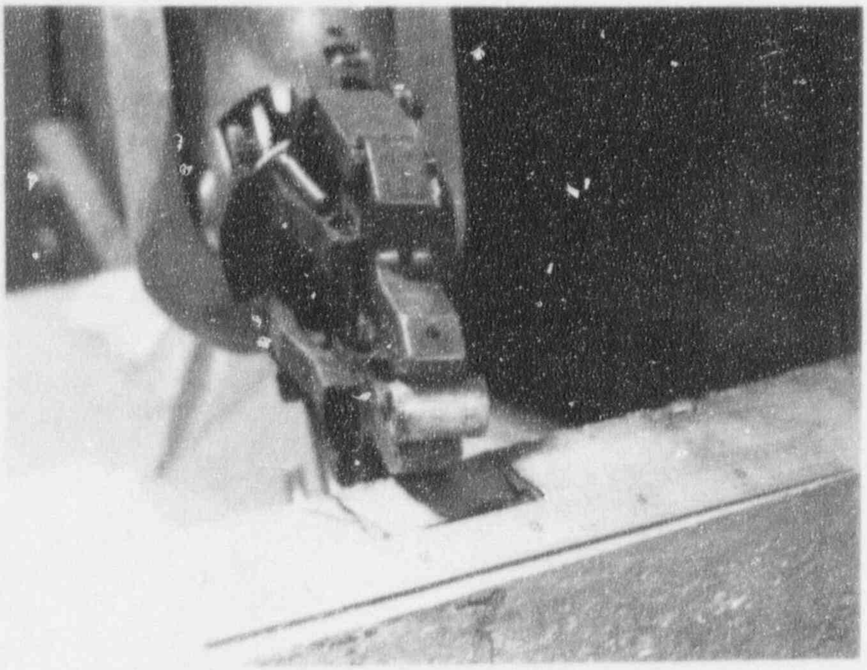
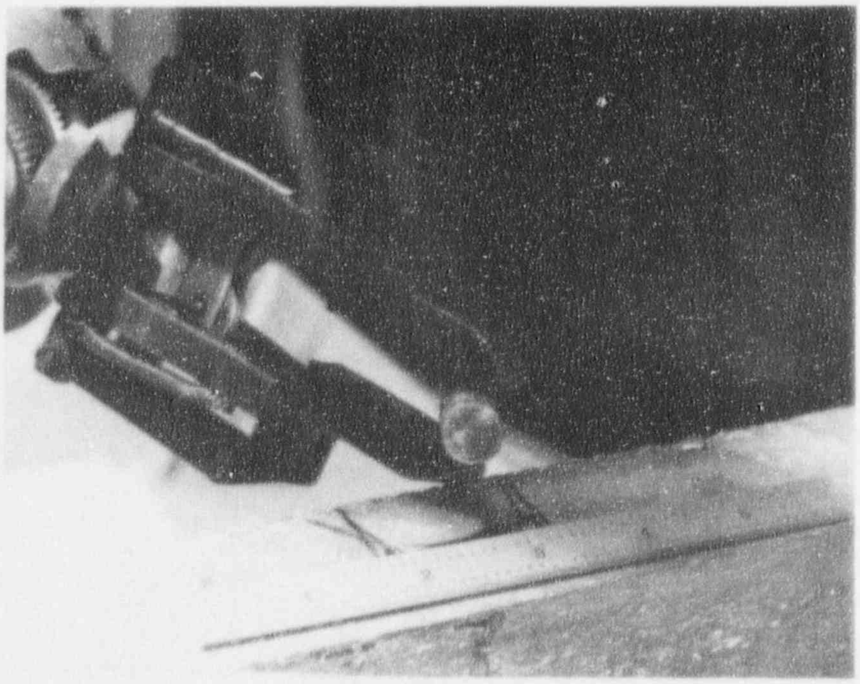


b)

FIGURE 7. PHOTOGRAPHS OF THE AS-SECTIONED ALUMINUM HOLDER.

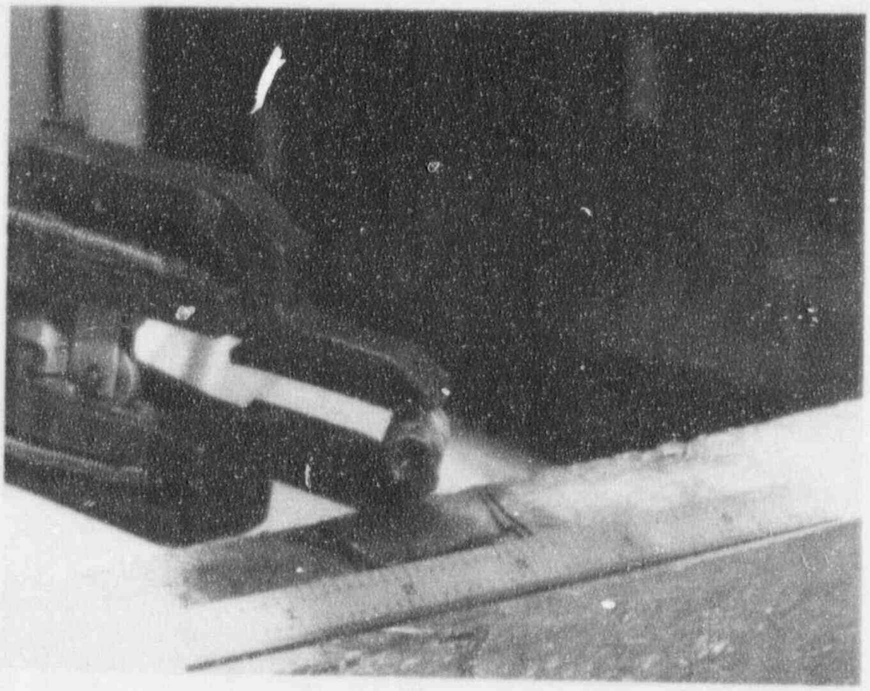


a) Side View



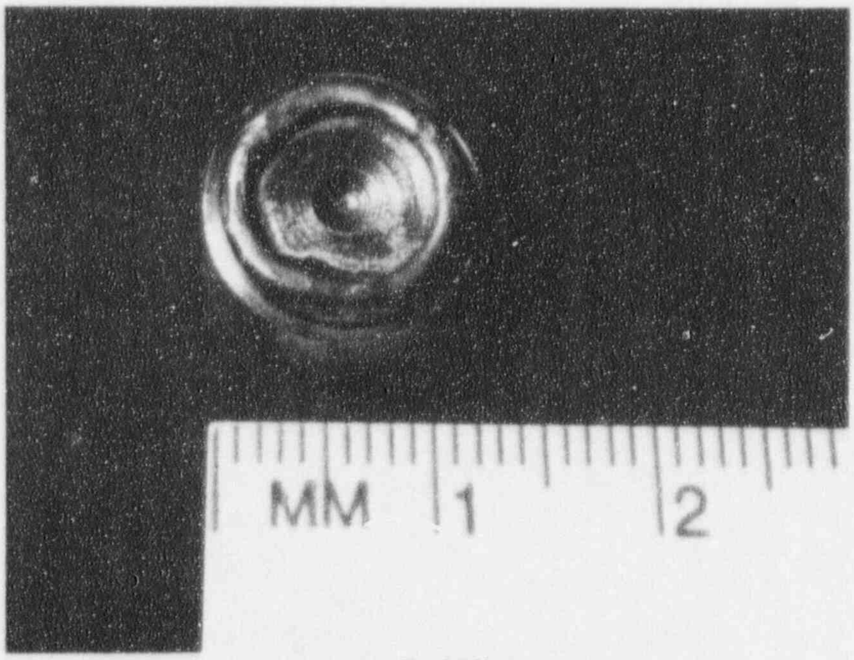
b) Top View

FIGURE 8. PHOTOGRAPHS OF THE DOUBLE ENCAPSULATED SOURCE. Notice Stamped No. SR 626 shown in Figure (a).

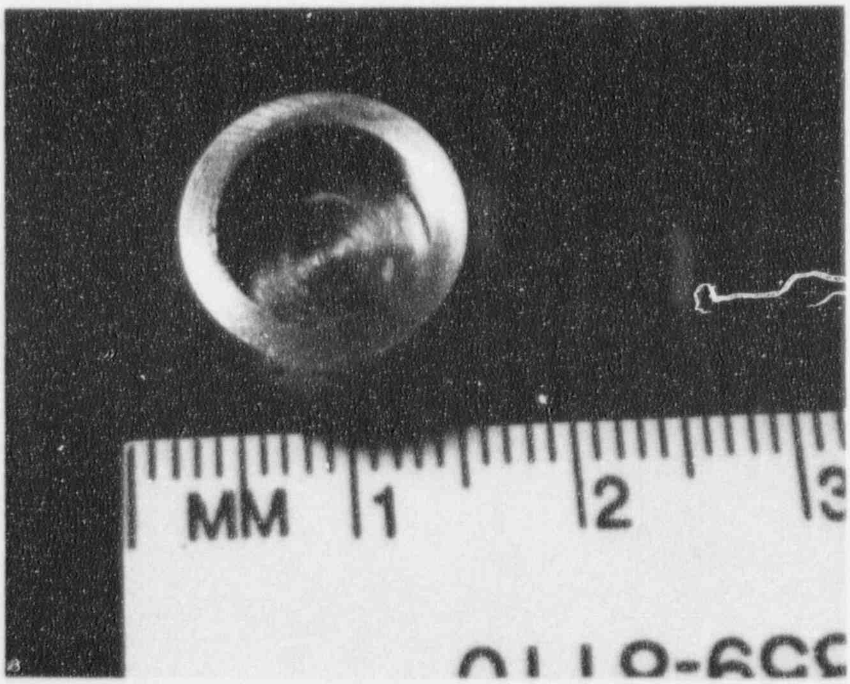


c) Welded End

FIGURE 8 (continued). PHOTOGRAPHS OF THE DOUBLE ENCAPSULATED SOURCE.

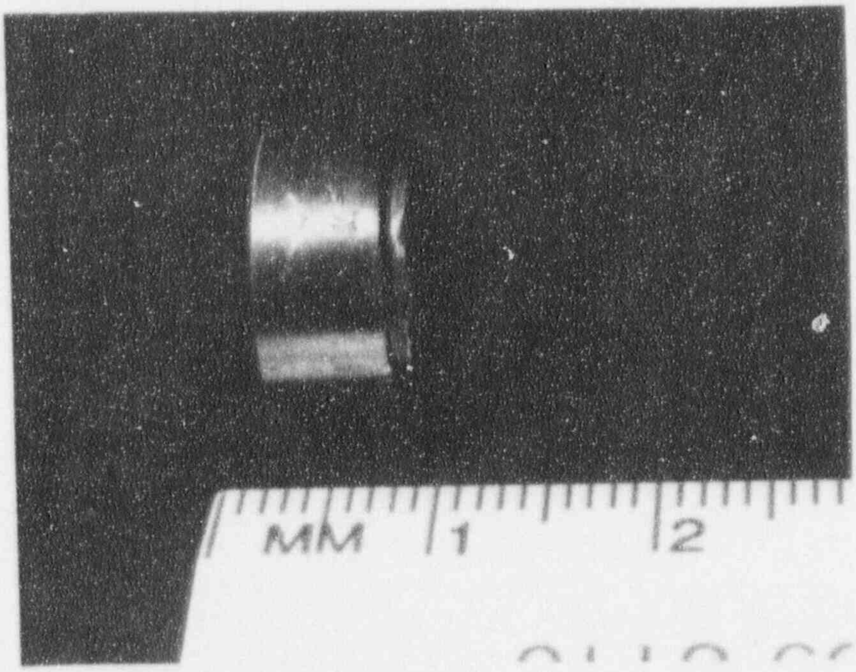


a) End View



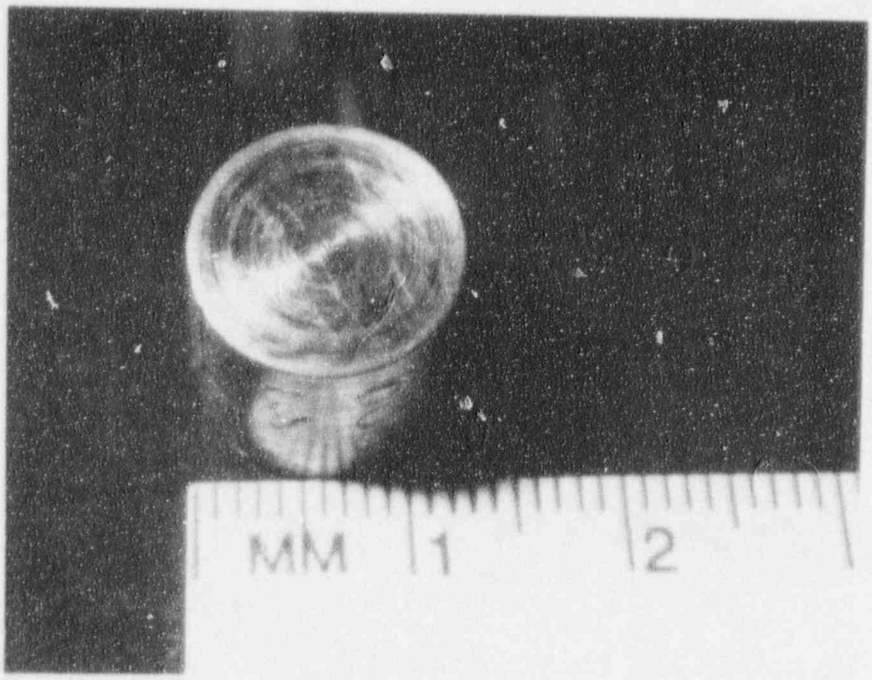
b) Inside View

FIGURE 9. PHOTOGRAPHS OF THE SECTIONED OUTER ENCAPSULATION WITH THE WELD.

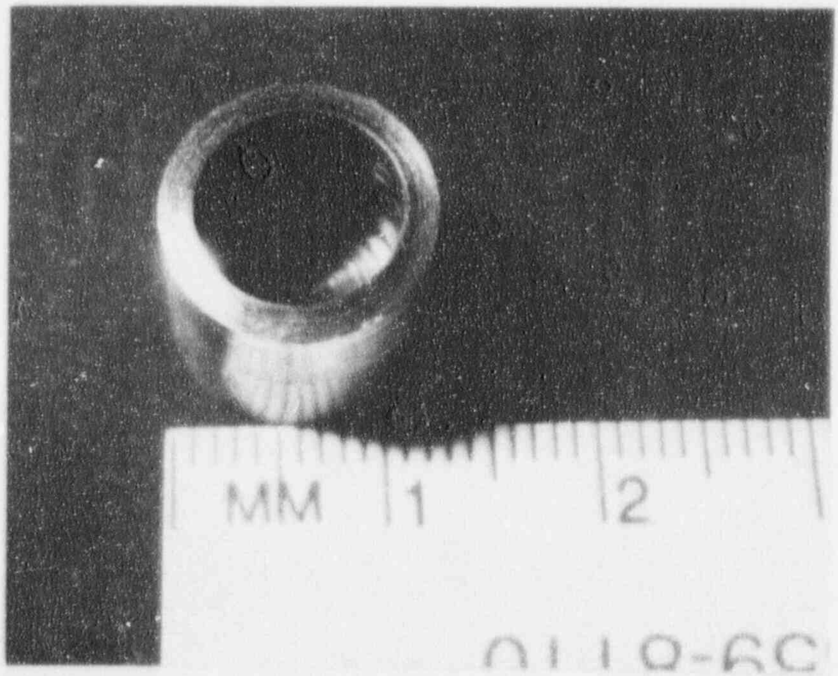


c) Side View

FIGURE 9 (continued). PHOTOGRAPHS OF THE SECTIONED OUTER ENCAPSULATION WITH THE WELD.

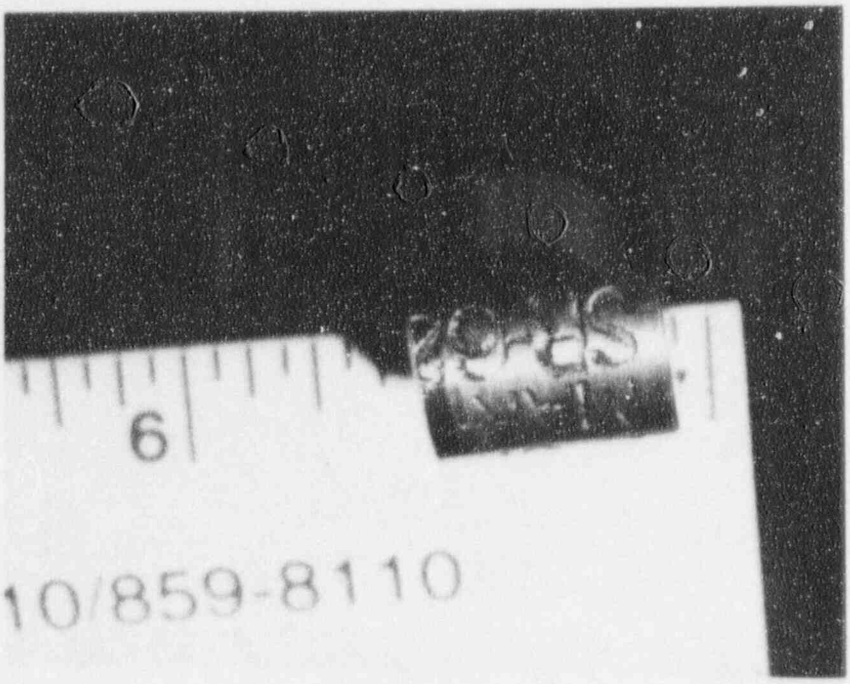


a) End View



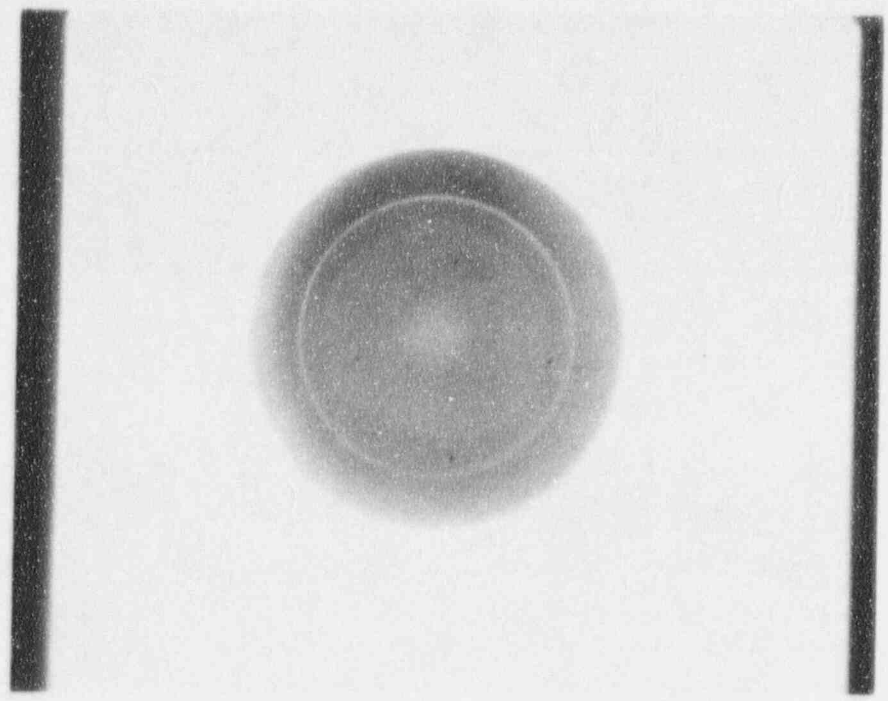
b) Inside View

FIGURE 10. PHOTOGRAPHS OF THE SECTIONED OUTER ENCAPSULATION TOP PORTION (NON-WELDED END).



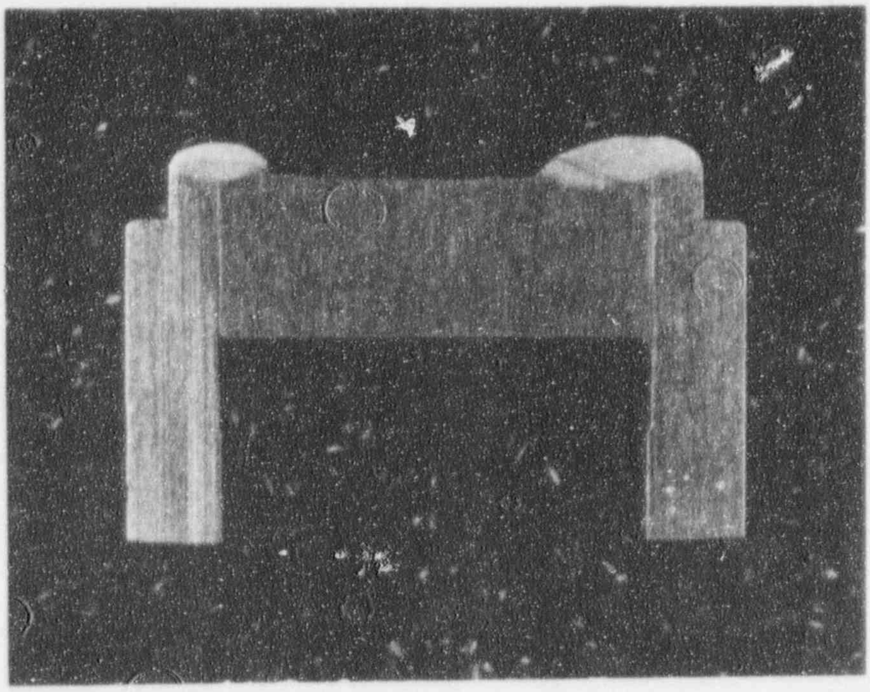
c) Side View

FIGURE 10 (continued). PHOTOGRAPHS OF THE SECTIONED OUTER ENCAPSULATION TOP PORTION (NON-WELDED END).



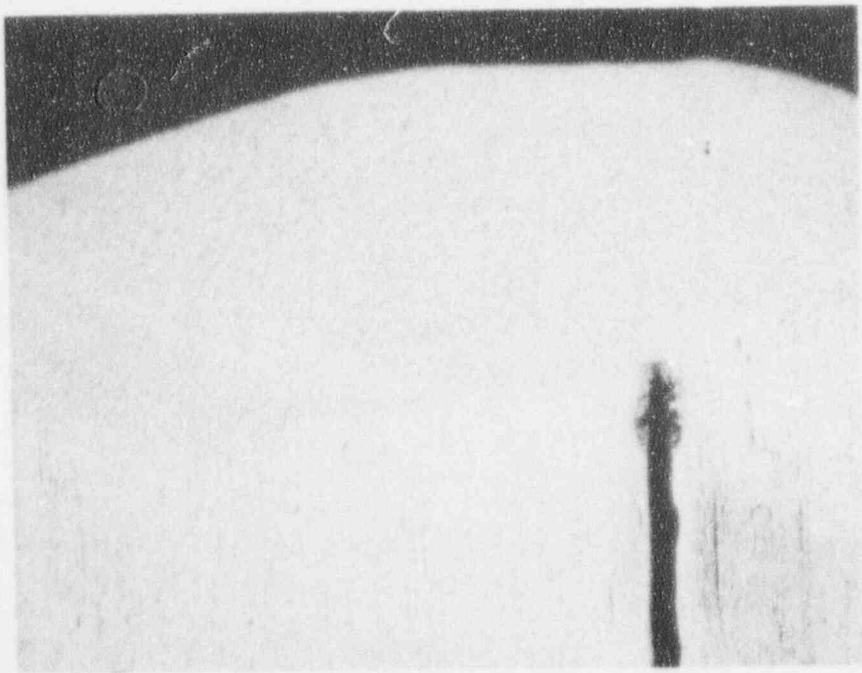
4X

FIGURE 11. RADIOGRAPH OF THE WELD IN THE OUTER ENCAPSULATION.
Notice no evidence of cracking.



70027 7X

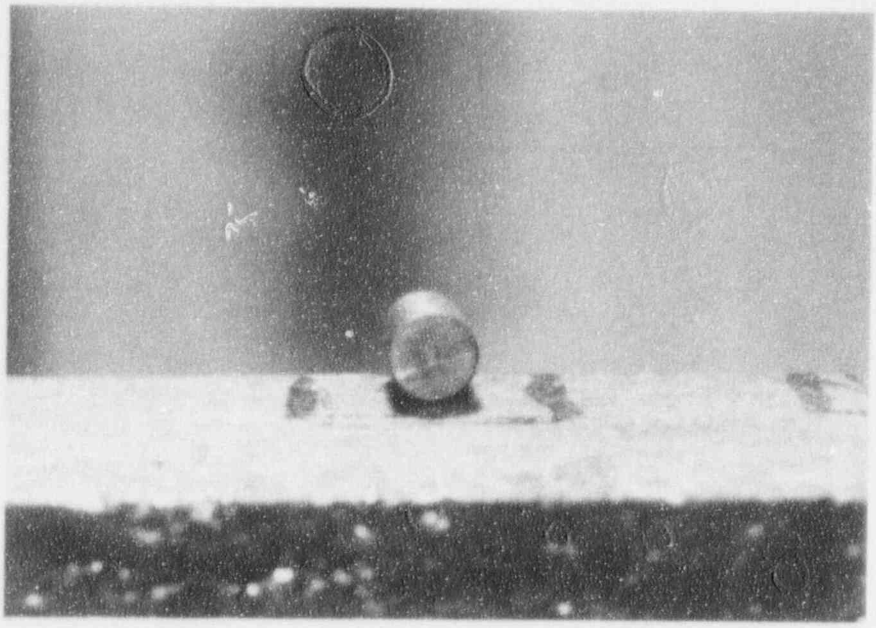
a)



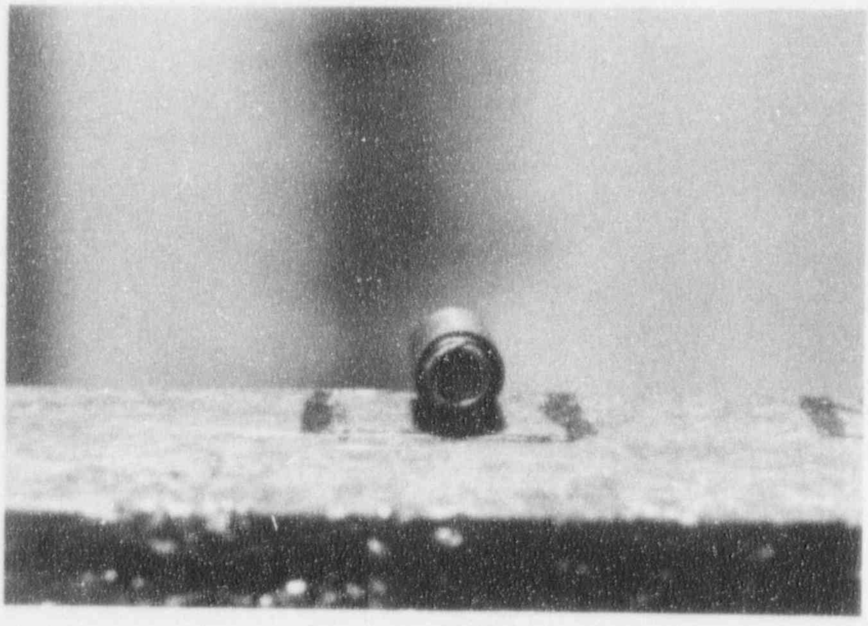
70213 50X

b)

FIGURE 12. PHOTOMICROGRAPHS OF THE CROSS SECTION OF THE OUTER CAPSULE AND THE WELD. Notice no cracks evident.

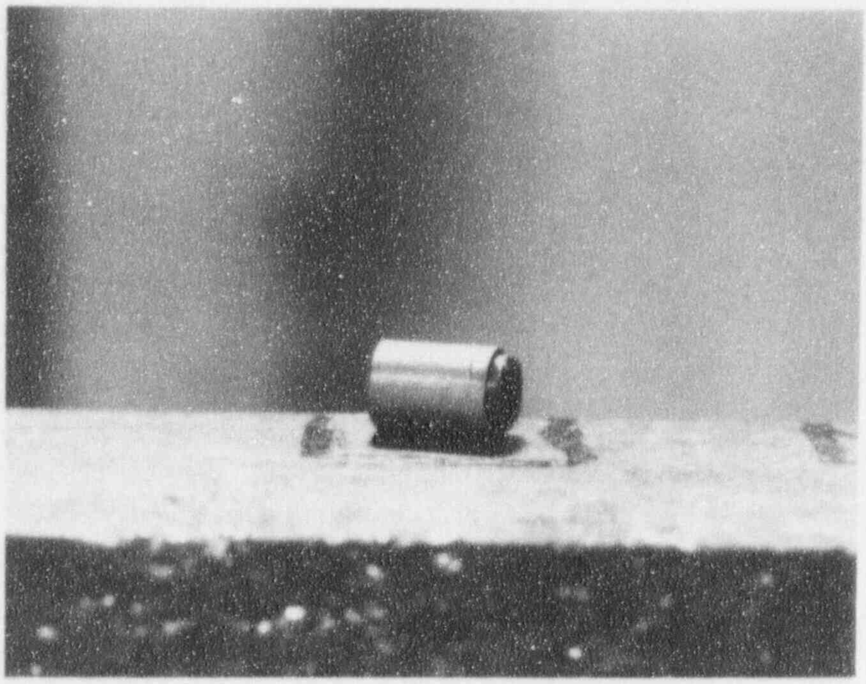


a)



b)

FIGURE 13. PHOTOGRAPHS OF THE INNER ENCAPSULATION.



c)

FIGURE 13 (continued). PHOTOGRAPHS OF THE INNER ENCAPSULATION.

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11. ABSTRACT (200 words or less)

This report covers the Task 4 activities for the Sealed Source and Device Safety testing program. SwRI was contracted to investigate a suspected leaking radioactive source that was installed in a gauge that was on a paper mill digester. The actual source that was leaking was not available, therefore, SwRI examined another source. SwRI concluded that the encapsulated source examined by SwRI was not leaking. However, the presence of Cs-137 on the interior and exterior of the outer encapsulation and hendling tube suggests that contamination probably occurred when the source was first manufactured, then installed in the handling tube.

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