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RADIOISOTOPE SOURCE SAFETY TESTING

K. W. Haff
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ISOTOPES DEVELOPMENT CENTER

RADIOISOTOPE SOURCE SAFETY TESTING

K. W. Haff
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Isotopes Division

MAY 1967

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RADIOISOTOPE SOURCE SAFETY TESTING

K. W. Haff, R. G. Niemeyer, and R. A. Robinson

ABSTRACT

This report covers the work of the Radioisotope Source Capsule Safety Testing Program, Oak Ridge National Laboratory (ORNL), through October 1966. Several hundred structural stress and temperature stress tests have been carried out on a wide variety of radioisotope source capsules. A method of classifying source capsules according to their containment integrity by using simple test procedures has been formulated.

1. SUMMARY

Information obtained from several hundred temperature and structural resistance tests on radioisotope source capsules has been used to develop a method of classifying source capsules into a few groups which describe the containment integrity of the capsules. The types of tests used are listed in Table 1.1.

Table 1.1. Source Capsule Tests

Strength	Temperature	Other
Crushing	High	Compatibility
Impact	Low	Leaching
Puncture	Thermal shock	Volatization (source material)
Shear	Temperature–humidity	
Tensile		
Vibration	Operating	
Abrasion		
Pressure		

In addition to conducting tests of the types shown in Table 1.1, older sources which had been in use and sources which had been in industrial

accidents were examined to obtain additional information about the containment performance of present day radioisotope sources.

While the various types of commercial sources exhibited a wide range of containment characteristics [depending on the type of radioisotope (alpha, beta, gamma) and the intended application], it was found that essentially all types could be categorized by five different temperature resistance classes and five structural resistance classes (Appendix A) without seriously penalizing any particular source type because it lacked one containment characteristic. When combined, the five temperature and five structural classes give 25 possible source capsule classifications. The classes relate only to the containment characteristics of capsules and not to the intended application.

Standard test procedures (Appendix B) have been developed which employ simple, readily available, and inexpensive equipment. It is expected that most of these tests can be easily carried out by source manufacturers to evaluate their source designs in terms of the 25 possible capsule classes. The tests cover all of the conditions listed under Strength and Temperature in Table 1.1 except abrasion and tensile strength. Abrasion testing was eliminated because tests showed this was a very unlikely mode of failure; the tensile test was eliminated because this property was more realistically indicated by the crushing and shear tests. It was not considered feasible to include a corrosion resistance test (other than oxidation in conjunction with the high temperature test) in the general capsule classification scheme because corrosion is more closely related to the specific application of the source than to incidental accident situations.

A simple vacuum leak test has been developed and is used to determine whether leaks are present in a capsule after it has undergone a classification test. This leak test is readily adaptable as a routine quality control test that will detect leaks down to the 10^{-6} (STP) cm^3/sec range.[1] For those few cases where the vacuum leak test cannot be used, a leaching test was evaluated and found to be an acceptable substitute.

In general, it was found that sources intended for medical application, excluding teletherapy sources, were most easily affected by temperature and structural stresses. In order of increasing resistance to stresses were beta gages, gamma gages, teletherapy and irradiator sources, gamma radiography sources, and well logging sources. There were exceptions to the general trend in most of the categories.

Specific tests were also carried out on sources that are not considered to be sealed sources within the meaning of the sealed source classification system (e.g., plated alpha calibration sources, foils, radiation-stimulated luminous paints). Although no attempt has been made to adapt the classification system to sources of this type, their ability to retain the radioactive material is of interest. Extensive testing of tritium-activated luminous paints under leaching, drying, aging, and elevated temperature conditions has shown that there is a wide difference in the tritium release rate among the various commercially available paints.

The release rate is not necessarily related to the specific activity of the paint; however, all of the paints met all specifications when they were evaluated in accordance with presently required acceptance tests.

In a few instances, sources that had been exposed to industrial accidents involving temperatures in excess of normal operating conditions were made available for examination. In 11 cases, sources had inadvertently been placed too close to steel furnaces with the result that the lead shielding in the source housing had melted. In eight of these cases, the sources themselves did not fail; in the other three cases there was no significant spread of activity. Of five sources involved in an industrial fire which completely demolished the building in which they were located, only two sources definitely failed, and there was only a minor amount of contamination in the rubble.

Inspection of a few sources that had been removed from service because routine wipe tests had indicated that they were leaking showed that in most instances the difficulty was the result of deficiencies in workmanship rather than the result of basic source design. In another instance, an obsolete type of lead O-ring sealed ^{60}Co teletherapy source was inadequate from a design standpoint in comparison with present day teletherapy sources.

Many of the source capsules which have been studied in this program were subjected to only a few tests to determine their failure limits for that particular type of test. A number of capsules representative of various types of commercial sources and applications were, however, subjected to the full series of classification tests. The results of these "trial classifications" indicate that the great majority of commercial source capsules will probably fall in the classification range between B-II and C-III. None of the sources tested would meet the stringent requirements for Class E-V; however, in one case a source intended for multicurie quantities of activity has met Class D-IV requirements. There were only four instances in which source capsules which were sealed when received failed to meet the minimum requirements (Class A-I) of the classification system. Of these four sources, only one was manufactured in the United States.

NOTE: No attempt has been made in this report to standardize the data by using just one system of measurement. All dimensions, test conditions, and readings are given in the units in which they were taken. Since this publication covers a period of several years, it is recognized that the instruments used and the units of measurement will vary throughout the report.

2. INTRODUCTION

The ORNL Radioisotope Source Capsule Safety Testing Program was started in 1962 to extend and expand earlier work that had been done for the AEC at Battelle Memorial Institute.[2] The major objectives established for the ORNL program were:

1. Determine the containment integrity of present-day commercially manufactured radioisotope source capsules under various conditions of stress.

2. Develop a method of grouping the wide variety of source capsules into a few classes (Source Capsule Classification System) which describe their containment integrity.

3. Develop simple tests that can be used by radioisotope source manufacturers to evaluate their products from the standpoint of containment.

4. Develop a method (Source Application Guide) of evaluating source applications, from the standpoint of consequences arising from capsule failure, which would relate the intended application to the class of source capsule that should be used.

This report describes the work that has been carried out through October 1966. The major effort has been concerned with the first three program objectives; work on the fourth objective is in progress.

In addition to work on these major objectives, tests have been conducted on both sealed and unsealed sources to provide specific information of interest to various groups in the AEC. In other projects, sources which had been in use for long periods of time or had been involved in industrial accidents were examined to obtain information for the Source Application Guide. Within the scope of this program, work has also been done to determine the containment integrity of shipping containers used for transporting radioisotopes and to develop shipping container designs. This portion of the program will be covered in a separate report.

There have been only a very few instances where by-product material radioisotope sources in commercial use caused contamination of property due to leaks in the source capsule. When one considers the many of thousands of sources that have been built and used in industrial and medical applications, this safety record speaks well for both the design of present-day sources and the care which has been exhibited by source manufacturers and regulatory agencies to ensure that only properly designed sources reach the commercial market. Since present-day sources have performed so well, it was decided that any system of classifying source capsules according to their ability to maintain containment under various conditions of stress should be based on the containment characteristics of existing sources. Also, since there is great diversity in the design, materials, and applications of radioisotope sources, it was desirable to

base any classification system on performance standards only and not on materials or methods of construction.

Early in the program, ORNL requested Battelle Memorial Institute to conduct a survey of various types of industries using radioisotope sources in their operations to determine the types of environment to which sources are exposed during routine use and the potential severity of accidents that might occur. During the course of this survey, 57 different facilities representing 18 types of industries using radioisotope sources were visited to view first hand the conditions under which the sources were being used. The results of this survey[3] showed that, in the large majority of cases, the routine use environments of sources are relatively innocuous and do not pose any difficult capsule containment-integrity problems. Therefore, it was decided that the system to be used to classify source capsules should be directed primarily toward defining what performance could be expected from a capsule under extraordinary accident conditions while, at the same time, indicating the long-term routine use environment in which the source capsule can be expected to operate satisfactorily.

The first phase of the ORNL program was to obtain, through normal procurement channels, representative types of sources from various source manufacturers and subject them to a variety of structural and temperature tests to determine the range of stresses which caused failure. Tests were purposely kept simple since one objective was to devise tests that could readily be used by source manufacturers without the need for expensive equipment. Tests were also kept general in nature so one procedure which was applicable to a wide variety of source sizes and shapes could be developed for each test. It became apparent during this phase of the work that a generalized test to evaluate the effect of a corrosive atmosphere was not possible because of the wide variation in atmosphere composition for different applications. Fortunately, in the great majority of applications, the nature of the atmosphere surrounding the source is not a significant problem; however, in those instances where a source is going to be used in a corrosive environment it will be necessary to conduct specific tests in addition to the more generalized classification tests described in this report.

Capsule leakage is the only criterion used to determine whether a source capsule fails one of the classification tests, and one of the early program tasks was to develop a reliable leak test that could be used to evaluate the capsule classification tests. After investigation, the vacuum leak test was determined to be the most versatile because it can be carried out rapidly on both radioactive capsules and nonradioactive "dummy" sources of various sizes and shapes with simple equipment. A study[1] to determine the sensitivity of this test showed that it could be reliably expected to reveal leaks down to the 10^{-6} (STP) cm^3/sec range. The vacuum leak test has been used to determine the results of classification tests throughout this program except for those few cases where the source design did not leave enough free volume inside the capsule for a stream of air bubbles to form. In these cases, a vacuum leach test was used to detect the presence of leaks. The sensitivity of the vacuum leak test can be brought almost to the level of helium and ^{85}Kr leak-detection methods [10^{-8} to

10^{-10} (STP) cm^3/sec] by the use of prepressurization techniques. It is felt, however, that the use of these more costly and time-consuming methods is not justified except in special circumstances. The hole sizes which correspond to leak rates in this range are more than an order of magnitude smaller than the effective pore sizes in "absolute" filters that are routinely used throughout the nuclear industry to filter gaseous effluents from radioactive operations prior to discharge to the atmosphere.

In addition to providing design performance guidelines to radioisotope source manufacturers and users, the Source Capsule Classification System may also be useful to various federal and state regulatory groups. At the present time, when these groups review license applications they frequently have little or no test data with respect to the containment integrity of the proposed design, and they must base their decisions on design drawings and previous experience with capsules of a similar design. Source classification gives these groups specific information to aid them in determining whether or not a source is adequate for its intended application. There will always be a few special types of sources that will not fit into a general classification system and will have to be evaluated by more specific tests; however, the ORNL Source Capsule Safety Testing Program has indicated that the greatest majority of commercial sources will fit into a classification system consisting of five temperature resistance and five structural strength classes.

3. TEST PROCEDURE DEVELOPMENT

There are many possible methods for testing the containment integrity of radioactive sources. The investigations at ORNL were designed to select those tests which would be useful in the source classification system and which would provide more knowledge on the reliability and applicability of the various tests in the broader areas of source testing. Where existing testing techniques were considered unsuitable for source classification, modifications were made or new test procedures were developed.

The tests which were finally selected for use in the ORNL Source Capsule Classification System (Appendix B) were chosen because they are simple to perform; provide reliable, reproducible results; and, for the most part, require inexpensive test equipment. Some test procedures and supporting data which did not become a part of the classification system are reported because they provide useful information in the area of source testing.

The selection of individual values in the ORNL Source Capsule Classification System is directly related to the excellent safety record associated with domestically manufactured sealed sources. Early work in the ORNL program was designed to define those characteristics of commercial source capsules which were responsible for the established safety record. The results of these investigations strongly influenced the selection of most of the values in the source capsule classification tables. The classification tests do, therefore, reflect current safe practice in sealed source capsule design.

In determining the values for the classification system tables (Appendix A), specific reasons can not be given for all selections. In some instances, the values were established as logical extrapolations of conditions for which specific reasons were given. The intention was to set parameters for each successive class so they would represent a consistent progression of characteristics, as they relate to containment, toward greater reliability under progressively more adverse conditions. The values are arranged so essentially all domestically manufactured sealed sources will fit somewhere in the classification system.

3.1. Leak Tests

A number of comparisons were made to determine the relative effectiveness and reliability of the various leak tests. The procedures detailed in 3.1.1 through 3.1.6 are the specific leak test methods used for the investigations and for the testing program; 3.1.7 summarizes the conclusions determined relative to this test area.

3.1.1. Vacuum Leak Test[1]

In detecting leaks in sealed radioisotope sources, the source to be tested is immersed in ethylene glycol or isopropyl alcohol, and the pressure above the liquid is reduced to ~125 mm of Hg absolute (equipment shown in Fig. 3.1). A leak is indicated by a stream of bubbles rising through the

liquid. The sensitivity of the test was 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 3×10^{-6} (STP) cm^3/sec can be readily detected, and leaks of 1×10^{-7} (STP) cm^3/sec have been detected by subjecting the capsule to a higher gas pressure immediately before the test.

Fig. 3.1. Typical Equipment Used for Vacuum Leak Test.

The relationship between the leak diameter (D), surface tension of the immersion liquid (T), and pressure differential required to initiate bubbling (ΔP) can be expressed by the empirical equation $\Delta P = 4T/D$. Isopropyl alcohol or ethylene glycol can be used as the immersion liquid because these compounds have relatively low vapor pressures and surface tensions.

The vacuum leak test can be used only if there is sufficient free volume in the capsule to support a stream of air bubbles in the event of a leak. The test has been used successfully on samples having free volumes as small as 0.1 cm^3; however, this is considered the minimum volume at which it should be used.

In cases where there is not sufficient free space in the capsule for the vacuum leak test, a small amount of an easily soluble cesium or lithium salt (e.g., cesium or lithium chloride) is added to the nonradioactive source compound in the prototype capsule being tested. The source is submerged in water in a vessel which is alternately evacuated and vented to atmospheric pressure for a period of 20 min. The water is then analyzed by a photometric technique capable of detecting cesium concentrations as low as 0.003 $\mu g/cm^3$. A soluble radioactive tracer ($^{137}CsCl$, $^{24}NaCl$) can be substituted for the nonradioactive tracer, and standard counting methods would then be used for analysis.

3.1.2. Smear Test

The source is wiped on all accessible surfaces with an absorbent paper disk 25 mm in dia. No attempt is made to "scrub" the source, but it is thoroughly wiped using moderate pressure on the paper. Although both wet and dry smear papers are used, wet smears consistently pick up a higher count than dry smears. However, in all comparison tests where the wet smear showed a leak, the corresponding dry smear also showed a leak.

3.1.3. Hot-Water Bubble Test

The source at room temperature is quickly immersed in water that is just below the boiling point (~90°C). If a stream of bubbles emanates from the source, due to expansion of air in the source, a leak is indicated. The sensitivity of this test is estimated to be $\sim 10^{-4}$ (STP) cm^3/sec. A low-temperature modification of this test involves placing the source in liquid nitrogen and then transferring it to a container of water.

3.1.4. Air-Pressure Bubble Test

This test is a variation of the previous test. The source is placed in a pressure vessel at 540 cm Hg air pressure for 15 min, then quickly transferred to the hot water. A leak is present if a stream of bubbles is observed.

3.1.5. Weight-Gain Test

The source is first weighed to an accuracy of at least 0.01 g, then placed in a water-filled pressure vessel at 1800 cm Hg pressure for 1 hr. The source is removed from the vessel and reweighed. A gain in weight indicates that water entered the capsule through a leak.

3.1.6. Test with Helium or Krypton-85

Welded or brazed capsules containing radioactive materials may be tested for leaks by incorporating helium into the capsule during or after sealing, then establishing conditions such that the helium can pass through any possible leaks into a controlled atmosphere. The gas can be detected with a helium mass spectrometer leak detector. A leak test[4] using ^{85}Kr may be performed in the same manner; however, in this case the ^{85}Kr is detected by counting. Although the equipment required for these tests

is quite expensive, the procedures are simple, readily adaptable to remote operations, and very sensitive.

3.1.7. Conclusions

The smear test does not always give indications of a leaking source capsule.

The weight-gain test is unreliable, particularly where there are small leaks or when there may be extraneous material on the capsule that can be dislodged by the water.

The air-pressure bubble test is only slightly more effective than the hot-water bubble test. The sensitivity of the air pressure test could probably be improved by increasing the pressure and performing the entire test in a single vessel.

Within its range of sensitivity, the vacuum leak test is the most reliable of the leak tests that were compared. The test is not effective, however, when the free volume inside the source is too small to support a stream of bubbles (e.g., in interstitial therapy needles). This test also may not be satisfactory in the case of a sizable leak which permits the air to be released in one or two large bubbles that could escape unnoticed.

The value of a thorough visual examination should not be discounted. In many instances, examination of seal areas under moderate magnification (5X-20X) clearly reveals defects.

3.2. Temperature Tests

3.2.1. Maximum Temperature Resistance

The maximum temperature resistance category is intended to define the maximum temperature at which the source capsule can be expected to maintain containment of the radioactive material for a short period of time under accident conditions. Fire hazard was of particular concern in this test. The lowest limit, 400°F, is slightly above the temperature associated with photoflood lamps, steam sterilizers, and protective grills and cases of room heaters. It is felt that sources which cannot maintain containment for a short period of time at 400°F would be subject to failure from so many extraneous conditions at the point of use that they should be evaluated individually according to the type and quantity of activity. The cut-off temperatures for each class are set at these values:

Class A	400°F	– slightly below melting point of most soft solders; above the softening point of most present-day plastics.
Class B	750°F	– below melting point of brazing and silver solders; above melting point of soft solders.
Class C	1700°F	– equivalent to a normal one-hour fire.

Class D 2400°F — short-term temperature limit for materials other than some superalloys and coated refractories.

Class E 4500°F — superalloy or coated refractory metal construction required.

The test is conducted in an electric furnace in air. The furnace is a standard laboratory type commonly found in any laboratory. It must be large enough, however, to allow air circulation through the chamber and around the source so maximum oxidation of the source capsule will occur during the test.

3.2.2. Operating Temperature Resistance

The operating temperature test is designed to subject a source to a temperature span which might reasonably be expected to occur during usage. The test is conducted in air in a standard laboratory-type electric furnace which has a large enough volume to ensure air circulation around the source.

The lowest (Class A) operating range was chosen because it represents a temperature span that is readily obtainable and over which any source might reasonably be expected to be used. The succeeding classes represent progressively more reliable units, from a safety standpoint, under conditions which increase up to the most severe sustained conditions. An application or environment is given with the temperature span of each class:

Class A 32 to 212°F — ice water mixture to boiling water.

Class B -40 to 212°F — lowest long-term natural environment temperature.

Class C -320 to 500°F — cryogenic to vacuum system "bake-out" temperature.

Class D -70 to 1700°F — conditions outside high performance aircraft; molten metal gaging.

Class E 32 to 2400°F — suggested operating temperature of some power conversion sources.

There are some types of sources for special applications that may not meet the minimum operating temperature range, and these would have to be evaluated individually in terms of the quantity of radioactive material and the specific application. The duration of the classification test is very short (24 hr) compared with the actual operating life of most radioisotope sources; therefore, the results can be considered as only an indication of the temperature range in which the source can be used. Any long-term, unusual corrosion or compatibility problems associated with the intended application would have to be evaluated separately.

3.2.3. Thermal Shock Resistance

Thermal shock test requirements are based on the possible thermal shocks that the capsule might encounter during normal usage or through accident. The test development proceeded along the lines of trial and error in which a source was subjected to heating and then quenching in a variety of "fluids" at low temperature. Air, ice-water mixtures, ice-salt-water mixtures, liquid nitrogen, trichloroethylene-Dry Ice mixtures, and Dry Ice were used. After quenching in a fluid, the source was transferred to an air atmosphere at -70°F. This atmosphere is obtained by packing a container in Dry Ice or in a trichloroethylene-Dry Ice mixture. The -70°F temperature is included to cover air transport and is the temperature normally experienced at an altitude of 40,000 ft. The other values are intended to include the operating temperature ranges for the individual classes. In Class E, the thermal shock is extended beyond the operating range to include a source falling into a cryogenic storage vessel.

3.2.4. Temperature-Humidity Cycling Resistance

The humidities chosen for this requirement represent the maximum and minimum values likely to be experienced in actual source usage. In the ORNL test program, the only sources which were affected by this test failed within 48 hr, so this time limit was arbitrarily chosen.

The temperature-humidity test is conducted in any chamber capable of being regulated to reproduce and maintain the test requirements of temperature and relative humidity in cycles. It was found that the only types of sealed sources that might be affected by this test are those that have threaded plug-type seals and those which use plastic or similar nonmetallic materials in their construction. This type of source will be found only in the first two temperature resistance classes (A and B) because other test requirements will exclude them from the higher classifications (C, D, and E). For this reason a temperature-humidity performance requirement is unnecessary for the higher classes.

3.3. Structural Tests

The structural requirements were arbitrarily chosen to reflect existing commercial source capsule strengths. The lower class limits represent relatively minor accidents which might occur in laboratories or light industry activities. The values in the highest class were chosen to represent puncture- and impact-type accidents that are credible in heavy industry, construction, and transportation activities. Classes were distributed evenly between these values. There is a wide structural requirement span between the lowest and highest class since beta sources are necessarily of lighter construction than compact gamma sources whose performance is not adversely affected by a thick capsule wall. (The majority of commercial beta sources tested at ORNL were in Classes I and II with only a few instances of a beta source meeting Class III requirements.)

3.3.1. External Pressure Resistance

Early work on pressure tests was performed using metallic sources which had a small tube welded into the capsule so internal hydraulic pressure tests could be performed. This method was time consuming, often weakened the capsules, and could not be readily used except on metallic capsules. For these reasons, an external pressure test (Fig. 3.2) was selected for use in the classification system.

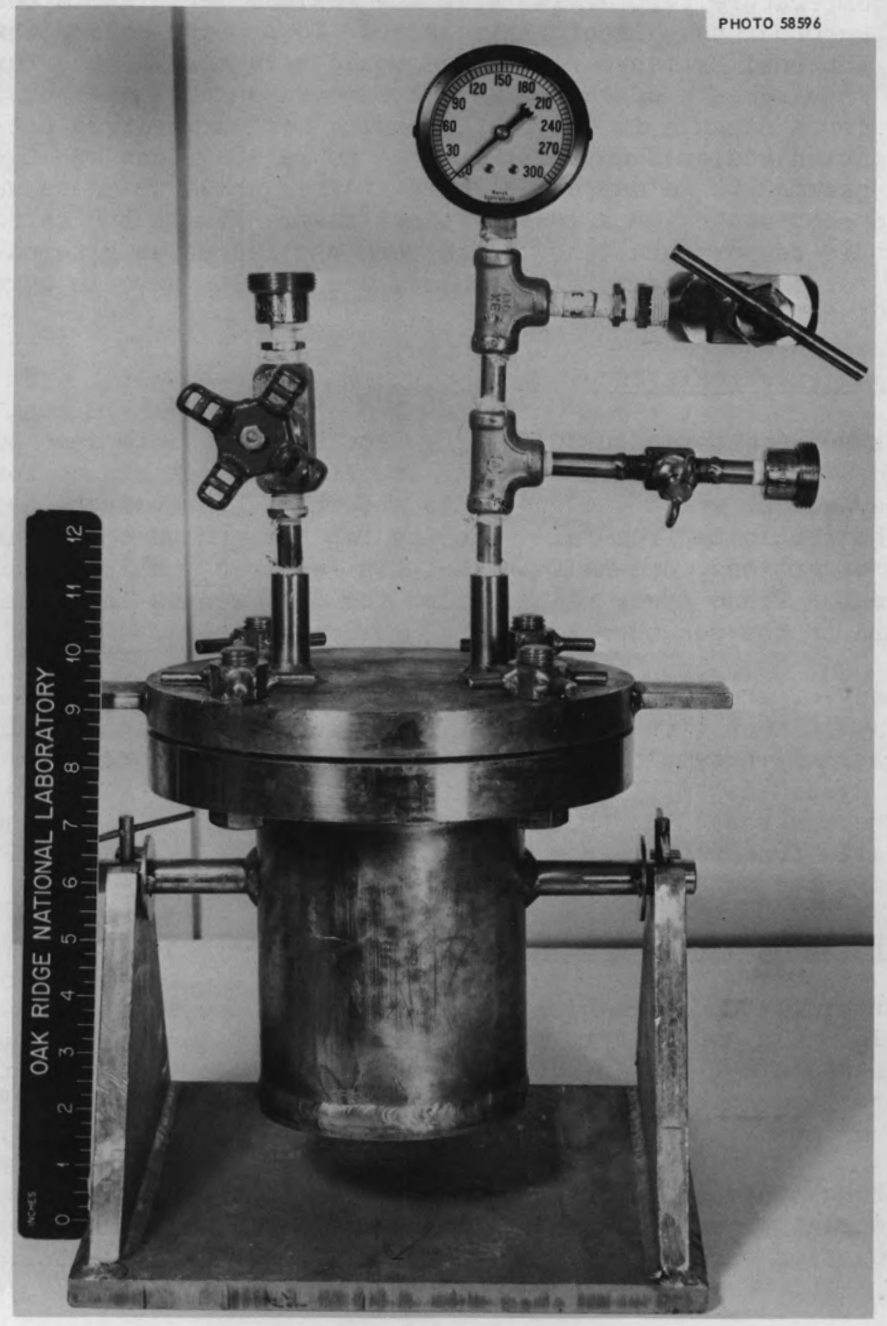


Fig. 3.2. Typical Equipment Used for Lower Ranges of External Pressure Resistance Test.

In addition to evaluating the external pressure resistance of a source capsule, these test results can also give an indication of the internal pressure which the capsule can withstand. Normally, the internal pressure resistance is indicated by the maximum temperature test results since the pressure in the capsule increases during this test due to expansion of the gas in the void volume and volatilization of the source compound. In some instances, however, a capsule fails to qualify for a particular temperature class because it fails some test other than the maximum temperature test or it fails the maximum temperature test for some reason other than internal pressure. To provide an indication of what the internal pressure resistance would have been, the external pressure requirements of each class were based on a calculated internal pressure for a capsule in the corresponding maximum temperature resistance classification (capsule material assumed to be stainless steel, original pressure assumed to be one atmosphere). After these stresses were corrected to compensate for a loss of tensile strength in the capsule material at this temperature, the values were applied as an external pressure. In tests performed on several capsules, the results were in agreement with the calculated values.

3.3.2. Puncture Resistance

This test represents a source falling from a height onto some small tool or stud. The test is similar to the impact force resistance test except for the area over which the energy is absorbed. The heights necessary to obtain the requisite free-fall velocity for the puncture test are, with only two exceptions, one-half the heights required for free fall in the impact test. These lower values allow for differences in the mechanism of failure in the puncture test.

Development of the puncture test encountered a difficulty that also occurred in the impact test — it was virtually impossible to drop a small source without having it tumble as it fell. The procedure adopted for the classification system is to place the most susceptible surface of the source on top of the puncture pin, then drop a metal cylinder onto the source. The weight falls freely through a tube which keeps the cylinder oriented until impact with the source.

3.3.3. Resistance to Crushing

This test simulates a crushing force which would be applied if a weight were accidentally applied to the capsule. In the lower class this is equivalent to a 200-lb man stepping on the capsule; at higher classes, it represents the crushing force of industrial vehicles or heavy objects on a source capsule.

The crushing test is performed by placing the source in a press (Fig. 3.3) which has flat pressing surfaces that are parallel. The source is oriented in the position which is considered to be most susceptible to failure.

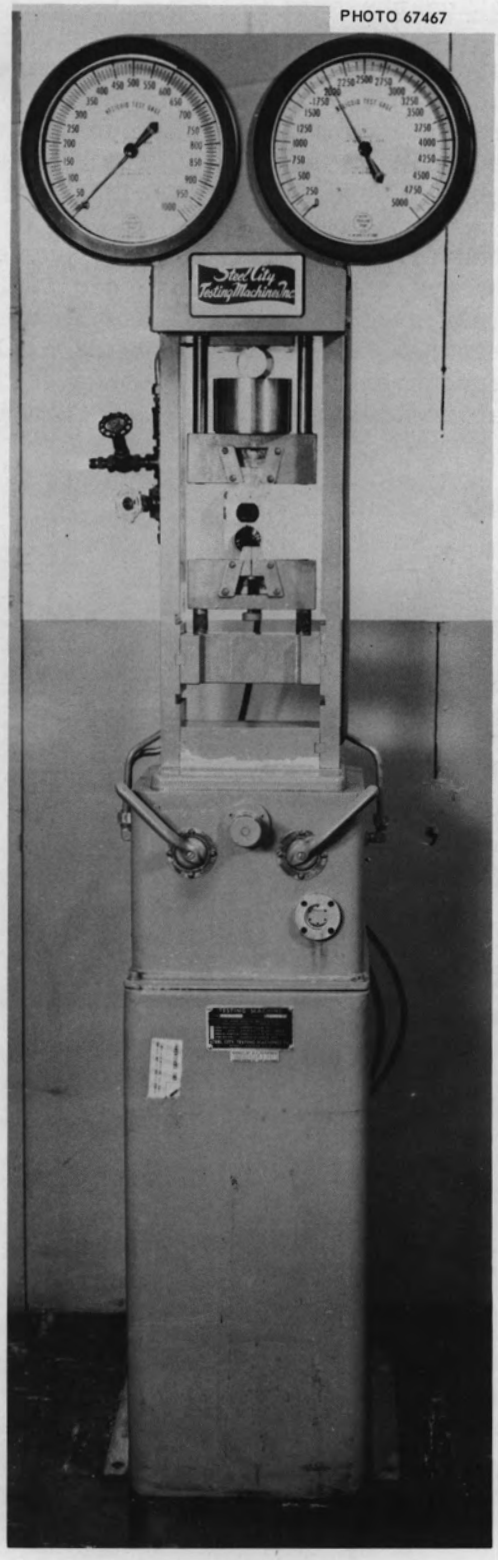


Fig. 3.3. Tensile and Compression Testing Machine Used in Performing Resistance to Crushing Tests.

3.3.4. Resistance to Shear

In order to be consistent with the relationship of shear strength to tensile and compressive strength, the values for resistance to shear were taken as 50% of the requirements for resistance to crushing forces. A typical shear failure could occur in a teletherapy unit if the capsule became dislodged and the shutter were closed on it.

The shear test selected for the classification system uses a set of shear blocks (Fig. 3.4) with 90° shear edges hardened to Rockwell C-65. One block is mounted solidly and holds the source in a fixed position so it cannot move during testing. The shear force is applied to the other block which is free to move downward in the direction of the shear. The shearing edges are circular so they more nearly conform to capsule geometry.

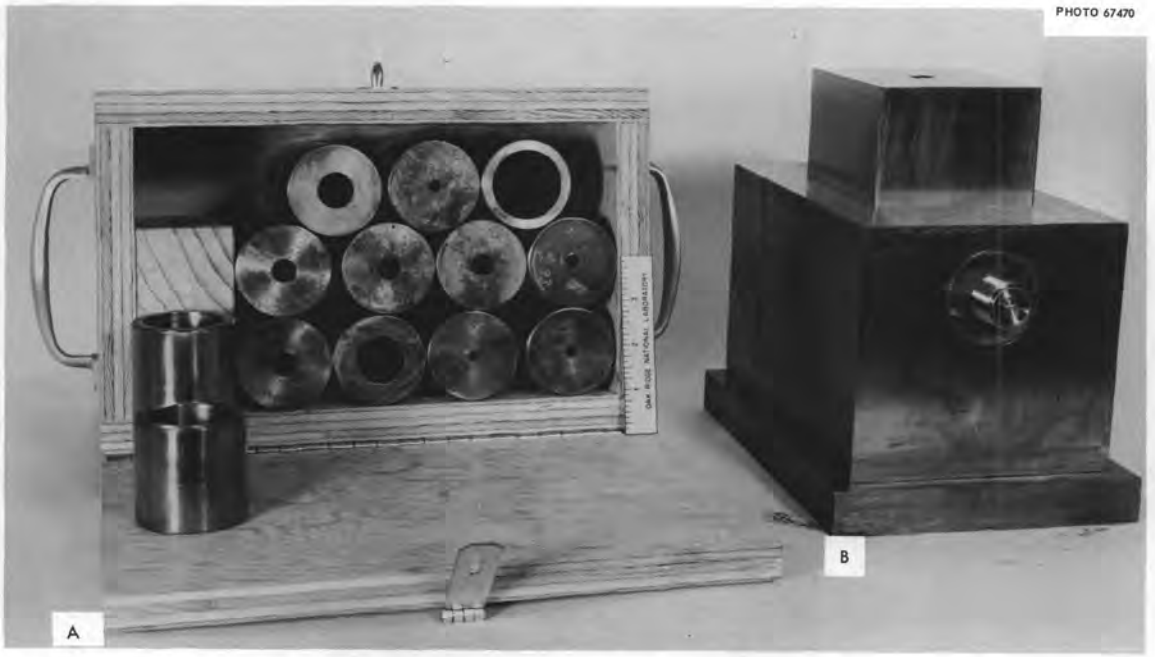


Fig. 3.4. Equipment Used for Resistance to Shear Tests (A — Source Holders, B — Shear Blocks).

3.3.5. Impact Force Resistance

The impact force resistance test is intended to ensure that source capsules can withstand impacts resulting from accidents in which the capsule falls from a height to an essentially unyielding object. The lowest value simulates a fall from a storage shelf. The intermediate values refer to falls from various heights in buildings which might be gutted by fire or to falls from open industrial-type construction. The highest value represents a fall from a gantry.

In developing the impact test it was found that dropping small sources onto a drop pad was not satisfactory for use in the classification system because there was no simple method to ensure that impact would occur on the most susceptible surface. Since the source would rotate while falling (depending on how it was released and the location of its center of gravity at the time of release), this method gave results which were not readily reproducible; and the impact often failed to involve the most susceptible surface.

In the impact test chosen for the classification system, the source is placed on an essentially unyielding test pad with the most susceptible surface up. A 2-in.-dia cylindrical weight is dropped vertically in free fall through a loosely fitting tube (Fig. 3.5), which guides it and prevents it from tumbling as it falls, so the flat end strikes the most susceptible surface of the capsule. A calibrated air driven ram (Fig. 3.6) has also been used to apply impact force for this test; however, it was found that the simpler weight-drop method provided satisfactory results.

3.3.6. Vibration Resistance

The requirements for vibration resistance are taken from an Air Force test for aircraft and missile parts. No tests are required for Classes III and IV because source capsules which normally fall into these classes are of rugged construction and are not normally subject to damage from vibration.

Fig. 3.5. Equipment Used for Impact Force Resistance Tests up to 60 ft-lb.

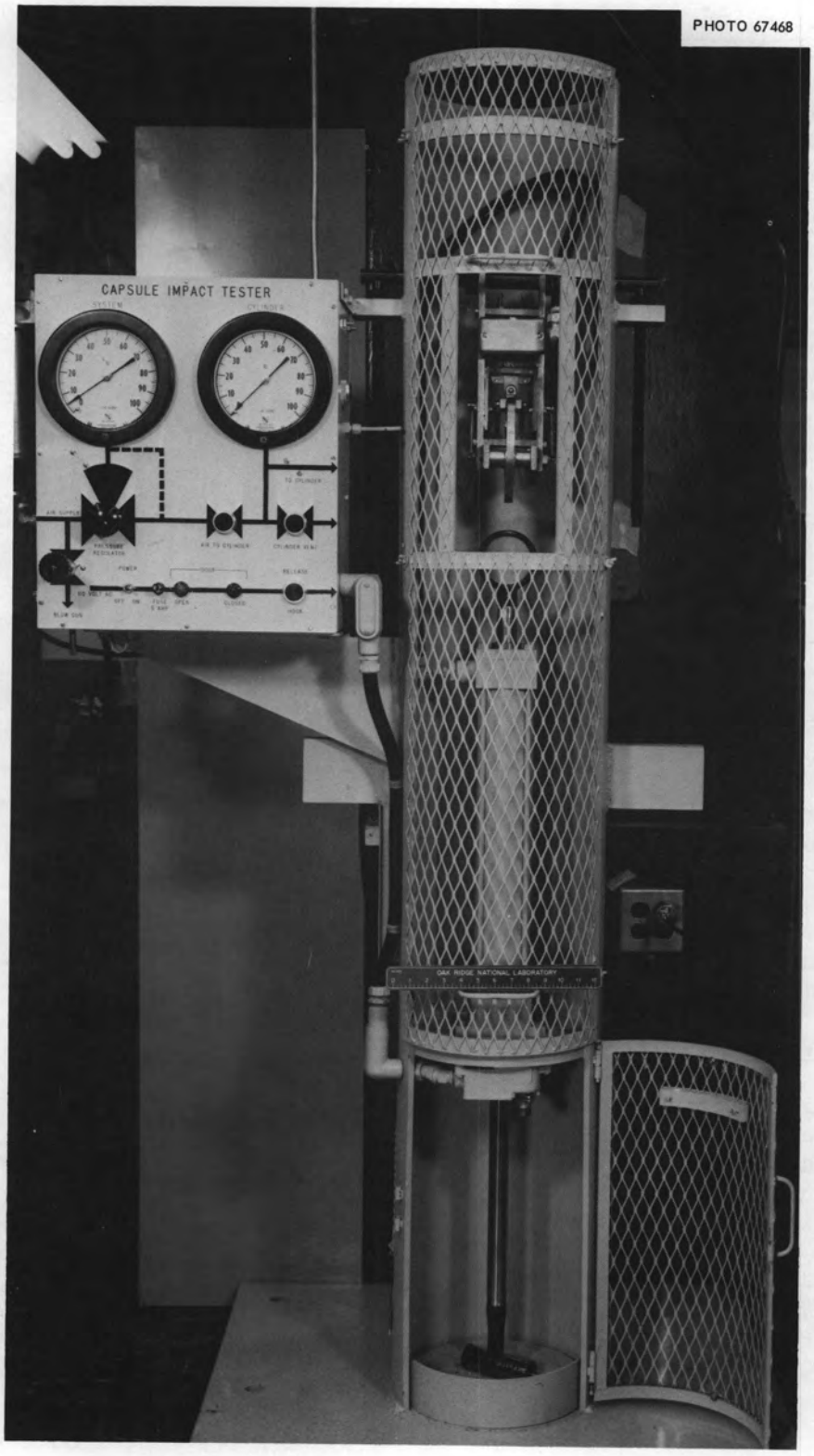


Fig. 3.6. Equipment Used for Impact Force Resistance Tests >60 ft-lb.

3.3.7. Abrasion Resistance

Abrasion tests, designed to define test requirements for the classification system, were performed on aluminum, brass, and stainless steel rods. Rods, 3/8-in. dia by 1-in. length, were used to simulate a typical source capsule shape. They were held at a 45° angle against a rotating disk covered with 180-grit abrasive paper (Fig. 3.7).

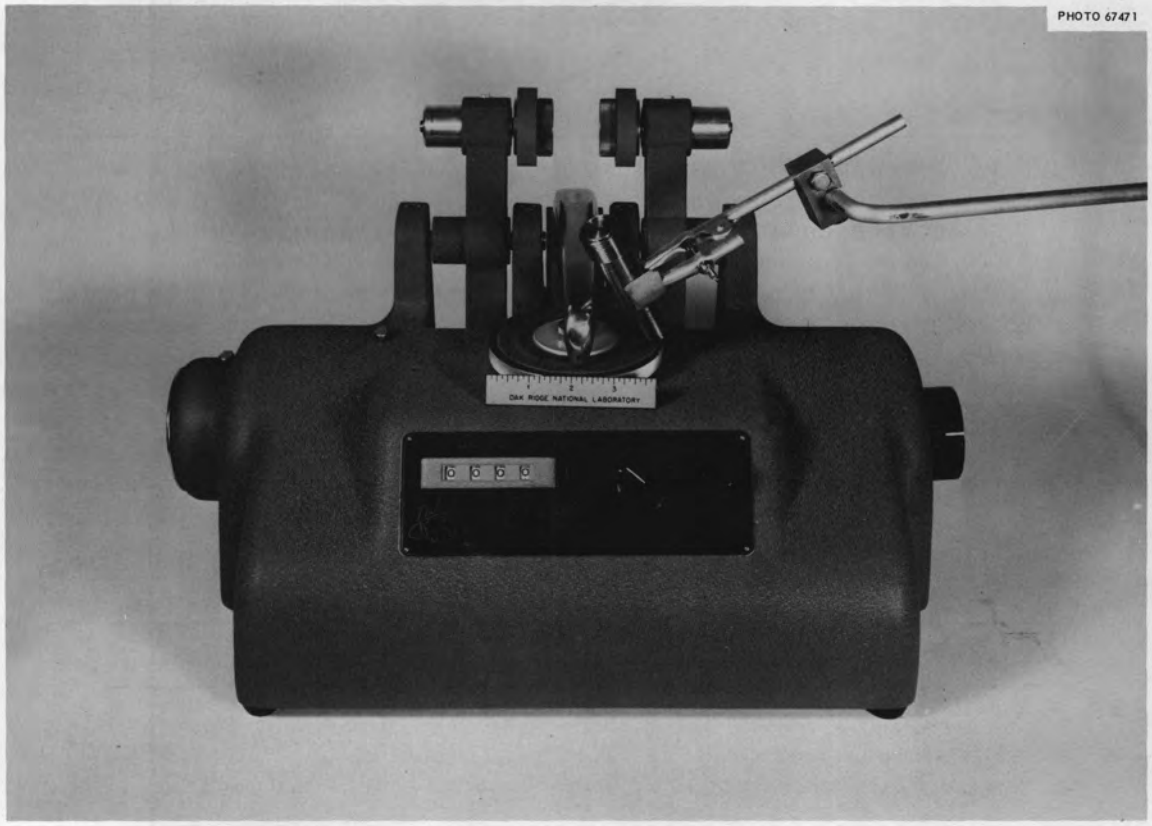


Fig. 3.7. Abrasion Resistance Test Equipment.

The pressure of the metal against the abrasive was varied by attaching weights to the rod. Table 3.1 shows average weight losses for ~4.8-g aluminum and ~15-g brass samples after 916 ft of travel (1000 cycles) using various weights on the rods.

The largest amount of aluminum removed in 1000 cycles was only 1/1000 of the starting material; the amount of brass removed was 1/400 of the starting material. Removal of brass was erratic since the surface of the emery paper became impregnated with brass and the paper had to be replaced every 4000 cycles.

Table 3.1. Average Weight Loss of Aluminum and Brass Samples in 1000 Cycles at 45° Angle Using 180-Grit Emery Paper

Aluminum Samples		Brass Samples	
Applied wt, g	Av wt loss, g	Applied wt, g	Av wt loss, g
0	0.0015	0	0.0172
5	0.0023	15	0.0247
10	0.0035	30	0.0285
15	0.0042	45	0.0377
20	0.0048	60	0.0344

Note: Placing a 5-g weight on the end of the lever arm opposite the brass sample gave a loss of 0.0161 g which corresponds to a 10-g sample without applied weight.

The amounts of weight lost in another series of tests using various weights on brass rods which were held in the vertical position are shown in Table 3.2. Approximately 2.8% (~28 mils) of the total weight of the brass sample was removed in one complete series of tests. If no weights had been added, ~6.4 mils would have been removed. In a similar series of tests on a stainless steel capsule, only barely measurable amounts of material were removed.

Table 3.2. Average Weight Loss of Vertically Placed Brass Samples in 1000 Cycles Using 180-Grit Emery Paper

Applied weight, g	Average weight loss, g
0	0.0039
15	0.0126
35	0.0383
50	0.0365

These tests indicated that abrasion would be an unlikely cause of source capsule failure, and on this basis the abrasion test was eliminated from the classification system requirements.

4. TESTING OF COMMERCIAL SOURCES

4.1. Medical Sources

4.1.1. Interstitial Needles

A special series of tests was devised to determine the structural strength of interstitial therapy needles (Fig. 4.1).

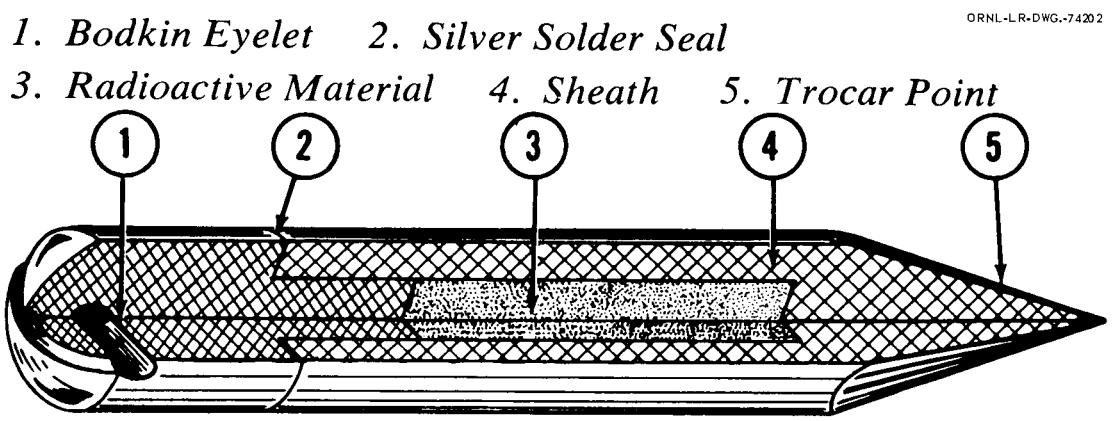
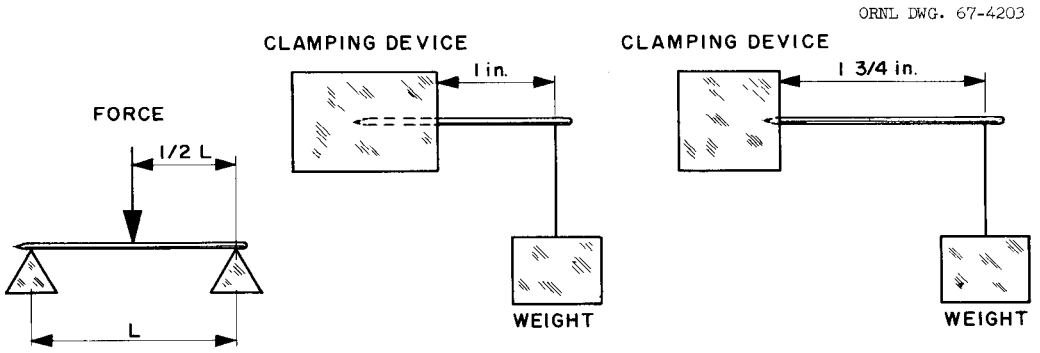


Fig. 4.1. Typical Cobalt-60 Interstitial Therapy Needle.

The impact test consisted of dropping weights onto the center of the needle which was supported on each end (Fig. 4.2.A); bend tests were carried out by suspending weights from the tip of the needle when the needle was clamped in a vise at a specific position from its point end (Fig. 4.2.B). The needle points were also subjected to a break test (Fig. 4.2.C) by holding the needle in a vise just behind the seal formed by the point and suspending weights from the opposite end.



A. Impact Test B. Bend Test C. Break Test

Fig. 4.2. Structural Tests for Interstitial Therapy Needles.

In the tensile test (Fig. 4.3.A), each end of the needle was secured in a clamping block and opposing forces were applied to the blocks. The shear test (Fig. 4.3.B) was similar to the resistance to shear test of the classification system — one end of the needle was securely held and a shearing block moved against the needle.

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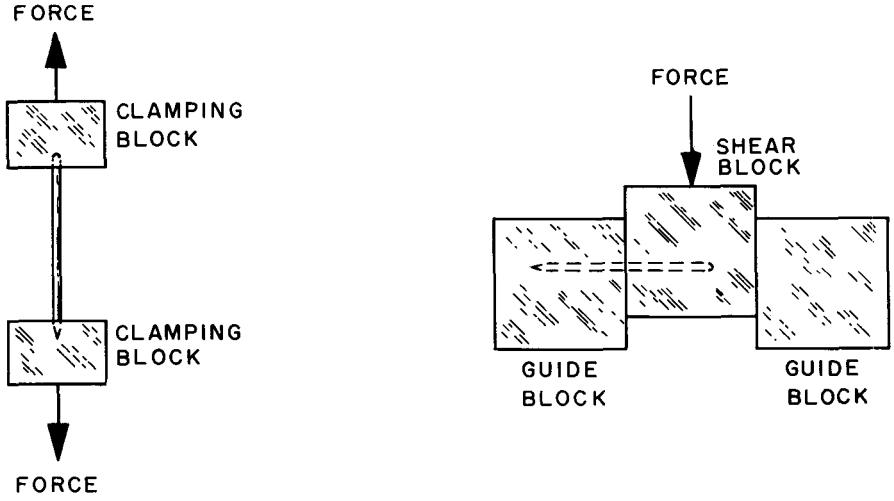

A. Tensile Test B. Shear Test

Fig. 4.3. Tensile and Shear Tests for Interstitial Therapy Needles.

For corrosion tests, one unit (M-Co-14) was implanted in a rabbit, and other samples were tested by immersion in blood plasma (Fig. 4.4 shows the equipment used). Additional tests were made to determine the effect of sterilization procedures.

Five types of cobalt therapy needles were submitted for testing and their physical characteristics are detailed in Table 4.1.

Table 4.1. Physical Characteristics of Therapy Needles

Source	Cobalt source material	Casing material	Length, cm	Outside dia, cm	Wall thickness, mm
M-Co-3	Metal wire	80% Pt–20% Ir alloy	2.9	0.165	0.3
M-Co-4	Alloyed wire	10-K gold	4.0	0.17	0.25
M-Co-6	Metal wire	Stainless steel	4.0	1.06	0.19
M-Co-14	Alloyed wire	9.5-K gold	4.0	—	0.18
M-Co-20	Metal wire	Stainless steel	1.8	0.127	0.10

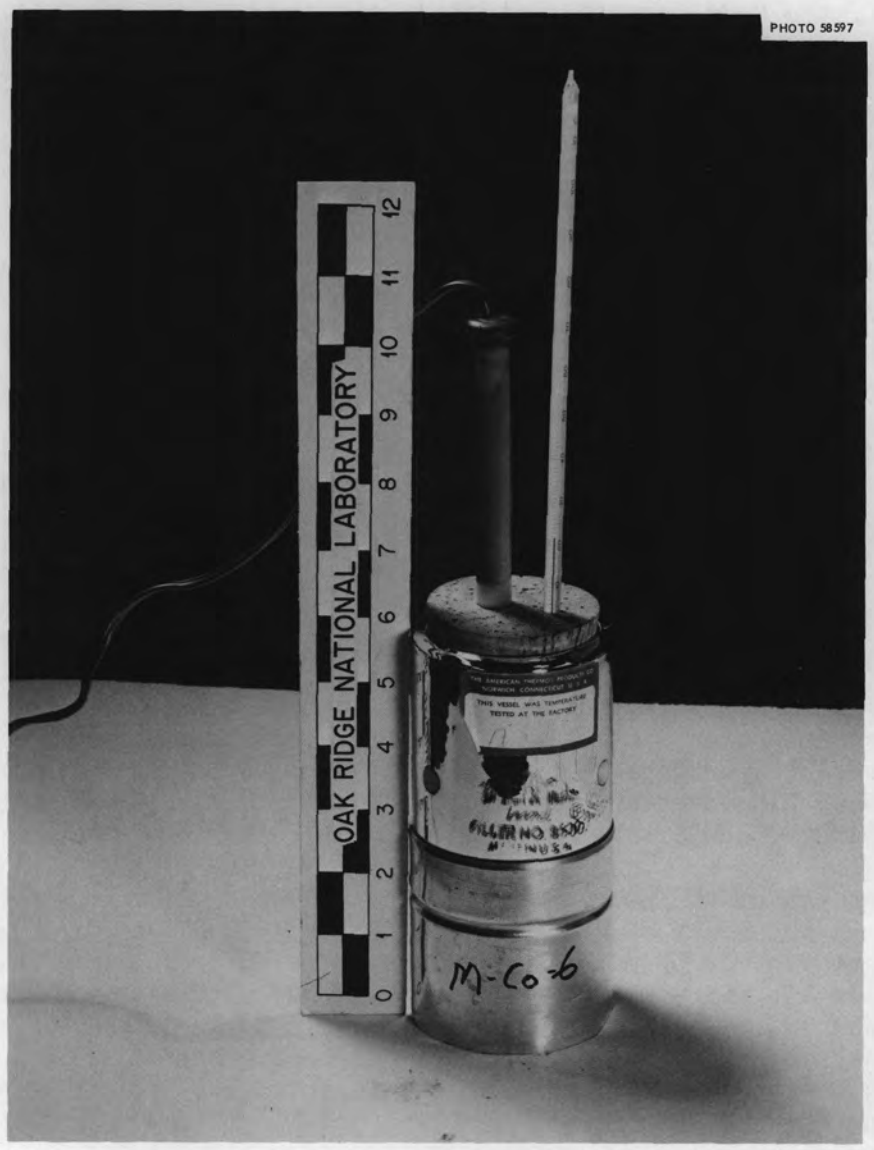

Fig. 4.4. Equipment Used for Blood Plasma Immersion Tests.

4.1.1.1. M-Co-3. Two samples of this model were received. Initial smear tests indicated 40 dis/min (M-Co-3A) and 30 dis/min (M-Co-3B). These sources were submerged in blood plasma for 16 hr at 98.6°F, and no radioactive contamination was found by scintillation counting of the fluid or by smear testing of the sources at the end of the period. No radioactive contamination could be detected after the needles had been autoclaved at 250°F and 20 psig for 30 min, and vacuum leak tests under ethylene glycol at 24 in. Hg pressure indicated no leaks were present in the samples.

A silver-soldered bodkin-type eyelet formed the capsule seal for these sources. This eyelet was removed on M-Co-3A and the cobalt wires were extracted. In a bend test with the needle casing held 3/4 in. from the

point end, the M-Co-3A casing started to bend when a 2540-g total weight was applied to the tip; it had bent to an angle of ~45° when the total weight reached 3290 g. The needle casing did, however, remain intact and did not split open.

M-Co-3B was subjected to an impact test in which a 60-g ball was dropped onto the center of the needle from a height of 6 in. A smear count of 33,370 dis/min indicated that the needle was leaking, but a vacuum leak test produced no evidence of a leak. After the needle had been cleaned to 150 dis/min, it was again impact tested by dropping the 60-g ball from a height of 12 in. The point end of the needle was smeared separately from the eyelet half and showed ~150 dis/min; the eyelet half (which included the seal) smeared 337,090 dis/min.

Three additional samples of this source model were obtained at a later date. M-Co-3-1A was subjected to a bend test (it began to bend at 12.5 lb and had bent to an angle of 20° when the total weight reached 20 lb) and a shear test (it sheared in two at 155 lb of force). In the tensile test on M-Co-3-1C, the eyelet of the needle pulled out at 195 lb of force; in the vacuum leak test on M-Co-3-1B, no evidence of a leak was produced.

4.1.1.2. M-Co-4. This needle had a soldered point for a seal. The unit was smeared when it was removed from the vendor's package, and no radioactive contamination was detected. After a boiling-water test at atmospheric pressure for 6 hr, retesting showed no radioactive contamination was present. The needle was then submerged in blood plasma for 16 hr at 98.6°F. At the end of the period, the fluids showed a count of 37 dis/min.ml.

The eyelet end of the needle was removed and the cobalt wires were extracted. A dry smear of the wires counted 65,000 dis/min. After the wires were autoclaved for 30 min at 250°F and 20 psig, they showed 1600 dis/min. The bare cobalt wires were then tested in body fluids for 16 hr, and the fluids counted 1849 dis/min.ml after the test period. One of the cobalt wires was flexed back and forth over a wipe paper until broken. The paper was then counted to determine if any pieces of the wire had flaked off during flexing, but no radioactive contamination was detected.

The empty needle sheath was subjected to the bend test by holding the needle in a vise just behind the seal formed by the point. A pan (~300 g) for weights was suspended from the point. Before any weights were placed on the pan, the point of the needle broke off. The needle was then clamped 3/4 in. from the broken point and weights were added to the pan. The needle split open when the total suspended weight reached 3660 g.

Three additional samples of this model were secured for testing at another time. M-Co-4-1A was vacuum leak tested and leaked badly. It was then subjected to a bend test and began to bend with a load of 8 lb. With an 18-lb load it bent enough to retain a set. In a tensile test on M-Co-4-1B, the point of the source broke off at 190 lb of force. The test was repeated without the point and the source pulled in two (approximately at the middle) with 210 lb of force. A force of 157 lb severed M-Co-4-1C when it was subjected to the shear test.

4.1.1.3. M-Co-6. Smear tests made of the source after removal from the vendor's shipping package and after testing in blood plasma for 16 hr indicated no radioactive contamination was present. The blood plasma counted 46 dis/min.ml after this test.

In a series of impact tests, a 60-g ball was dropped on the center of the source from heights of 6 to 36 in. varying by intervals of 6 in. Flattening of the needle was observed starting with the first drop; however, failure was not detected until a visible crack occurred after the drop from 36 in. A smear taken after the crack appeared showed no radioactive contamination.

The cobalt wires were removed from the needle and dry smeared. The count was 130,000 dis/min. The wires were then tested in blood plasma at 98.6°F for 16 hr, and the fluids counted 7.6×10^5 dis/min.ml at the end of the period.

Additional tests were made on three other samples of this source at a later date. M-Co-6-1C and M-Co-6-1A were leak tested by the vacuum leak test method, and no leaks were detected. In a bend test on the latter source, the needle began to bend at 3 lb of weight and was bent to a 20° angle by a total weight of 12 lb. A force of 205 lb was required to shear M-Co-6-1B in the shear test.

4.1.1.4. M-Co-14. This model had a silver soldered stainless steel point and a removable stainless steel eyelet. An initial smear test indicated no radioactive contamination; after the source had been boiled in water for 6 hr, neither the water nor the needle showed evidence of radioactive contamination.

The needle was implanted in the back of a rabbit so the eyelet end protruded from the skin; however, the rabbit tore the needle out during the night. It was reimplanted in the lower intestinal region and the incision was sewed up. After one week, the needle was removed and tissue samples were taken from the area in which the needle had been placed. Neutron activation analysis of the tissue samples showed 3 ppm of gold (presumably from the needle), but scintillation counting of the samples indicated no radioactive contamination.

The cobalt wires were removed from the sheath and dry smeared; no radioactive contamination was detected. The wires were then tested in blood plasma at 98.6°F for 16 hr. At the end of the test, the wires smeared 3830 dis/min and the fluids counted 2900 dis/min.ml. After an autoclave test at 250°F and 20 psig for 30 min, a smear count of the wires showed 6580 dis/min. One of the wires was flexed back and forth over a clean paper until it broke. The paper was counted and results showed 3680 dis/min from particles that had flaked off during the procedure.

In a bend test on the needle sheath, the point broke off when a total weight of 2060 g was applied; the sheath split open under a total weight of 2160 g.

Five more samples of this model (designated M-Co-14-1A through M-Co-14-1E) were acquired for testing. Only M-Co-14-1D leaked (at the eyelet end) during the initial vacuum leak tests. M-Co-14-1E was subjected to the temperature-humidity test, and no damage was noted. Table 4.2 summarizes the results of structural tests on these additional samples.

Table 4.2. Results of Structural Tests on Cobalt Applicator Needles (M-Co-14)

Source	Tensile test[a]		Bend test		Point break,[b] lb	Shear test[c]	
	lb	psi	lb	angle, °		lb	psi
		x 10^3					x 10^3
M-Co-14-1A			12	45	1	175	39.8
M-Co-14-1B	238	54			110	180	40.9
M-Co-14-1C			12 22	began 20		207	47
M-Co-14-1D						356	~81

[a]to separation; [b]to break; [c]to shear.

4.1.1.5. M-Co-20. All five samples of this source (Fig. 4.5) were found to have defective end welds (Fig. 4.6).

Fig. 4.5. M-Co-20 Source as Received.

Impact tests were made on M-Co-20A with a 60-g weight dropped from heights of 1, 2, 3, 4, 5, 6, 12, 18, and 24 in. In the first five drops, only small dents were made in the needle; at 6 in. the needle began to bend slightly; after 12, 18, and 24 in. the needle had bent to 30°. However, no cracks developed in the stainless steel sheath.

In a shear test on M-Co-20B, a total force of 190 lb was required

Fig. 4.6. Defective End Weld (M-Co-20).

to sever the needle. Based on the needle's cross-section area of 0.00196 in.^{2}, this represents a calculated shear strength of 96,000 psi.

M-Co-20C was placed in 15 ml of blood plasma at 98.6°F for 24 hr to test for corrosion. Activation analysis of the fluid indicated 0.13 ppm cobalt, an amount which could be expected to result from the defective end weld.

4.1.1.6. M-Y-105. Each of the four yttrium medical applicator needles (length, 1-5/16 in.; dia, 0.040 in.) obtained for testing (Fig. 4.7) contained 3 mc ^{90}Y. All needles leaked at both ends in the initial vacuum leak tests. Microscopic examination of the needles showed that the point end of the needle had been sharpened by machinery after assembly, and a crack existed at this joint of each needle. A crack was also found in each unit where the eyelet was joined to the body of the needle. It was not possible to determine positively whether the joints were soldered or friction fitted; however, it is believed that they were friction fitted.

Fig. 4.7. M-Y-105 as Received.

One needle sheared under 70 lb of force, and the eyelet of another needle pulled out under 39 lb of force. In a break test, the point end broke 1/8 in. above the point at 110 lb of force. The needle bent to ~20° under 7 lb of weight.

4.1.2. Interstitial Thread

An interstitial therapy thread (M-Ir-5) consisting of stainless steel-encapsulated ^{192}Ir seeds (~3 mm long) spaced ~3/8 in. apart inside a hollow nylon thread was tested. The initial smear of the source indicated no radioactive contamination was present.

One of the seeds was removed from the nylon string and it counted ~200 dis/min when smeared. After the seed was submerged in blood plasma for 24 hr at 98.6°F, the seed smeared 230 dis/min and the blood plasma counted 11,530 dis/min.ml. A second seed was removed from the string (smear test

showed 110 dis/min) and autoclaved at 250°F and 20 psig for 30 min. No radioactive contamination was evidenced after the test.

The entire nylon string with the ^{192}Ir seeds inside was then placed in the autoclave for sterilization. The string, which smeared 110 dis/min at the beginning of this test, broke in the area of one of the ^{192}Ir seeds when being resmeared after the test. To test whether the sterilization had weakened the string to such an extent that it would break under only a very small amount of applied force, the section of nylon string which had been cut off to remove the first seeds was placed in the autoclave. A tensile test following autoclave sterilization determined that a force of 3550 g was required to break the string. The nylon string with the seeds inside was also subjected to a tensile test. A force of 475 g broke the string in the immediate area of an iridium seed, releasing the seed positioned at that point. It was concluded that radiation damage to the nylon string was the problem area.

4.1.3. Interstitial Seed

M-Au-103 was an unencapsulated metallic gold seed (0.031 by 0.10 in.) used in implantation work. The total activity was not determined. The source was immersed in 10 ml of blood plasma at room temperature for 24 hr. At the end of the period, analysis of a sample of the fluid showed no detectable ^{198}Au.

4.1.4. External Applicators

4.1.4.1. M-Sr-10. This source was a right circular cylinder (0.2-in. dia; 0.5-in. length) containing ^{90}Sr doubly encapsulated in a 0.002-in. stainless steel outer capsule and a 0.010-in. aluminum inner capsule, both sealed by welding. An 8-in. stainless steel handle (0.25-in. dia) was attached to one end of the unit. Figure 4.8 shows the source with the handle removed. The source was smeared with soft absorbent paper, but no radioactive contamination was detected. After being subjected to the blood-plasma test, the source smeared 120 dis/min, and the blood plasma counted 1380 dis/min·ml. After the autoclave sterilization test, no radioactive contamination could be detected by smearing. A 4-hr boiling-water test was negative, and the smear count at the end of the test indicated no radioactive contamination.

A 60-g weight was dropped on the source from heights which varied in 6-in. increments from 6 to 36 in. There was no visual damage to the source after any drop, and the highest smear count recorded after a drop was 20 dis/min. A vacuum leak test after the 36-in. drop showed a leak in the top outer rim. The autoclave test was repeated but the subsequent smear on the source indicated no radioactive contamination.

Fig. 4.8. M-Sr-10 With Handle Removed Before Testing.

4.1.4.2. M-P-107. This was a circular contact therapy source (2-3/4-in. dia) containing ^{32}P. It was constructed of two disks of plastic material (1/16 in. thick) bonded together; one disk was red, the other clear (Fig. 4.9). The material was soft and spongy, and it tore readily. When observed under a stereomicroscope, several holes in the transparent disk appeared to go all the way through the layer. Table 4.3 summarizes the test results on this type of source.

Fig. 4.9. M-P-107 as Received.

Table 4.3. Results of Tests on Therapy Source M-P-107

Source	Test conditions	Results
M-P-107A[a]	Smear	820 dis/min
M-P-107A[a]	Soak in 50 ml H_2O for 24 hr	No detectable activity
M-P-107-1A[b]	400°F for 1 hr	Melted
M-P-107-1B[b]	100°F for 24 hr	No damage
M-P-107-1C[b]	Radiation damage test in 10^6 r/hr field for 24 hr	No change in material strength; bad odor

[a]Active source — dose rate output of 500 r/hr·cm^2.

[b]Inactive source.

4.1.5. Teletherapy

4.1.5.1. Cesium (T-Cs-86). This type of source contained CsCl doubly encapsulated in stainless steel cylinders with welded closures. A 0.020-in.-thick window was machined in one end of each capsule, providing a total "window thickness" of 0.040 in. Each assembly was 1.5 in. in dia by 1.5 in. in height and weighed ~195 g. Thirteen samples of this type were tested, nine in the first series of tests and four in the second.

Five samples in the first series were subjected to temperatures between 1000 and 1380°F (in air in an electric furnace) for periods of one hour or more. Source F bulged slightly at the window after 30 min at 1150°F, and source A bulged out in the same area after one hour at 1380°F; however, neither source ruptured and no leaks could be found. Other than discoloration, no other changes or damage could be detected.

Source A was placed in the furnace at 1470°F for 45 min. At the end of this time, a smoke-like vapor was observed coming from the source. Microscopic examination revealed a small hole in the center of the source window at the point where the vapor was observed. Removal of the outer capsule showed that the inner capsule had ruptured on the rim of the window (Fig. 4.10), obviously from pressure caused by expansion of melted CsCl. When samples B and 1B were subjected to a temperature of 1700°F for 1 hr, melted CsCl expanded and ruptured the capsule of B and bulged the window on 1B. Microscopic examination located three holes near the center of the window in 1B, and these holes leaked in the vacuum leak test.

Fig. 4.10. T-Cs-86-1B With Top of Outer Capsule Removed (After Being Subjected to 1700°F for 1 hr).

Source 1C was placed in a furnace at 1000°F for 1 hr, then packed in crushed Dry Ice at -40°F for 24 hr. Following this test, the unit was heated to 212°F and quenched in ice water at 32°F. No damage to the source could be detected following these tests.

Three samples were subjected to puncture tests. Sources C and 2A were placed window down on a 1/8-in.-dia pin. A 194-g weight was dropped from a distance of 15 ft onto C, and a 582-g weight was dropped from a height of 5 ft to strike 2A. Capsule 2A was indented 0.105 in. but neither source was penetrated; no leaks were detected when the samples were subjected to a vacuum leak test. The fourth sample was placed window down on a 1-in.-dia surface and a 6-lb weight was dropped from a distance of 12 ft onto the source. The window "caved in" 1/8 in. as a result of this test, but no evidence of a leak was produced in the vacuum leak test. The source was examined microscopically, but no cracks or breaks were found.

In shear tests, unit 2A was first subjected to 1000 lb of applied force for 1 hr and then 10,000 lb for 1 hr. After the second test, the capsule was indented a distance of ~0.1 in. at the point of shear, but the capsule did not open and no leaks could be detected. In a test to failure on sample E, the source sheared at 19,344 lb of applied force. In an internal pressure test, the outer capsule of source 1A ruptured at 2000 psig, and the inner capsule ruptured at 3150 psig. Both capsules opened along a side.

The second group of samples was obtained to classify the source model under the ORNL Source Capsule Classification System and to verify the results of the original tests. The sources were subjected to all of the Class B temperature tests. No damage to the capsules was evident, and no leaks were detected by vacuum leak tests made after each test.

The Class III structural tests produced a slight indentation or flattening following some tests, but in only one instance was there rupturing of the capsule or evidence of a leak. When a 12-lb weight was dropped from a height of 5 ft striking the window end of one source, the window remained undamaged but the opposite end of the capsule was ruptured by the shearing action of the weight and the capsule lid. Two other impact tests with the weight striking a horizontally positioned source slightly flattened the sources, but the capsules did not rupture and no leaks could be detected.

This teletherapy source model was classified B-III in the classification system.

4.1.5.2. Nine-Year-Old ^{137}CsCl Source. A nine-year-old ^{137}CsCl source (1540 curies) was examined in order to determine the effects of aging on stainless steel radioactive source capsules.[5] This teletherapy source contained two ^{137}CsCl pellets encapsulated in two concentric stainless steel (type 316) containers. The inner capsule was plugged with a 316 stainless steel plug (~1.5 in. long) and sealed with silver solder; the cap for the outer capsule was a threaded plug of 410 stainless steel and the capsule was sealed with silver solder. The dimensions of the pellets and the capsules are given in Table 4.4, and a cross-sectional view of the source is given in Fig. 4.11.

Table 4.4. Dimensions of the $^{137}CsCl$ Teletherapy Source

Capsule	Length, in.	OD, in.	ID, in.	Window thickness, in.
Inner	2.575	1.500	1.260	0.020
Outer	3.265	1.750	1.520	0.020

Pellets	Dia, in.	Height, in.	Weight, g	Activity, curies
1	1.250	0.531	33.07	760
2	1.250	0.504	27.86	780

When received by ORNL, the outer capsule of this source appeared to be in excellent condition; no corrosion or discoloration could be detected. The capsule smeared 1920 dis/min. The source was tested for leaks by immersion in ethylene glycol in a glass vacuum vessel at a pressure of -25 in. Hg (~5 in. Hg absolute). No leaks were detected by this method. In removing the outer capsule, a corner of the inner capsule was cut off. The inner capsule leaked in the area of the cut, but no other leaks were observed.

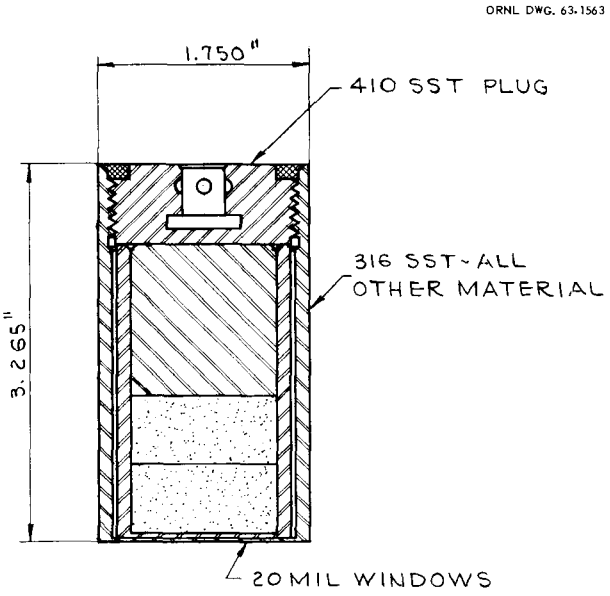

Fig. 4.11. Cross-Section View of 1540-curie $^{137}CsCl$ Teletherapy Source.

Visual examination of the exterior of the inner capsule revealed no evidence of corrosion or deterioration of the capsule. The capsule smeared 5×10^5 dis/min due to the cut in the source. After the inner capsule of the source was opened and the pellets were removed, it was observed that the upper edge of one pellet and the adjacent area on the capsule were the only affected (discolored) areas. The window and the inside of the capsule were bright and shiny. Inspection of the capsule under 80X magnification did not reveal any pitting or cracking of the inside surface of the capsule or the window. The capsule was decontaminated by ultrasonic cleaning, and a photograph of the capsule at 80X magnification was made (Fig. 4.12). Metallurgical examination indicated no change in the crystalline structure and no deterioration of the capsule wall or window. Photomicrographs (100X magnification) of the crystalline structure of the material are shown in Figs. 4.13-4.15.

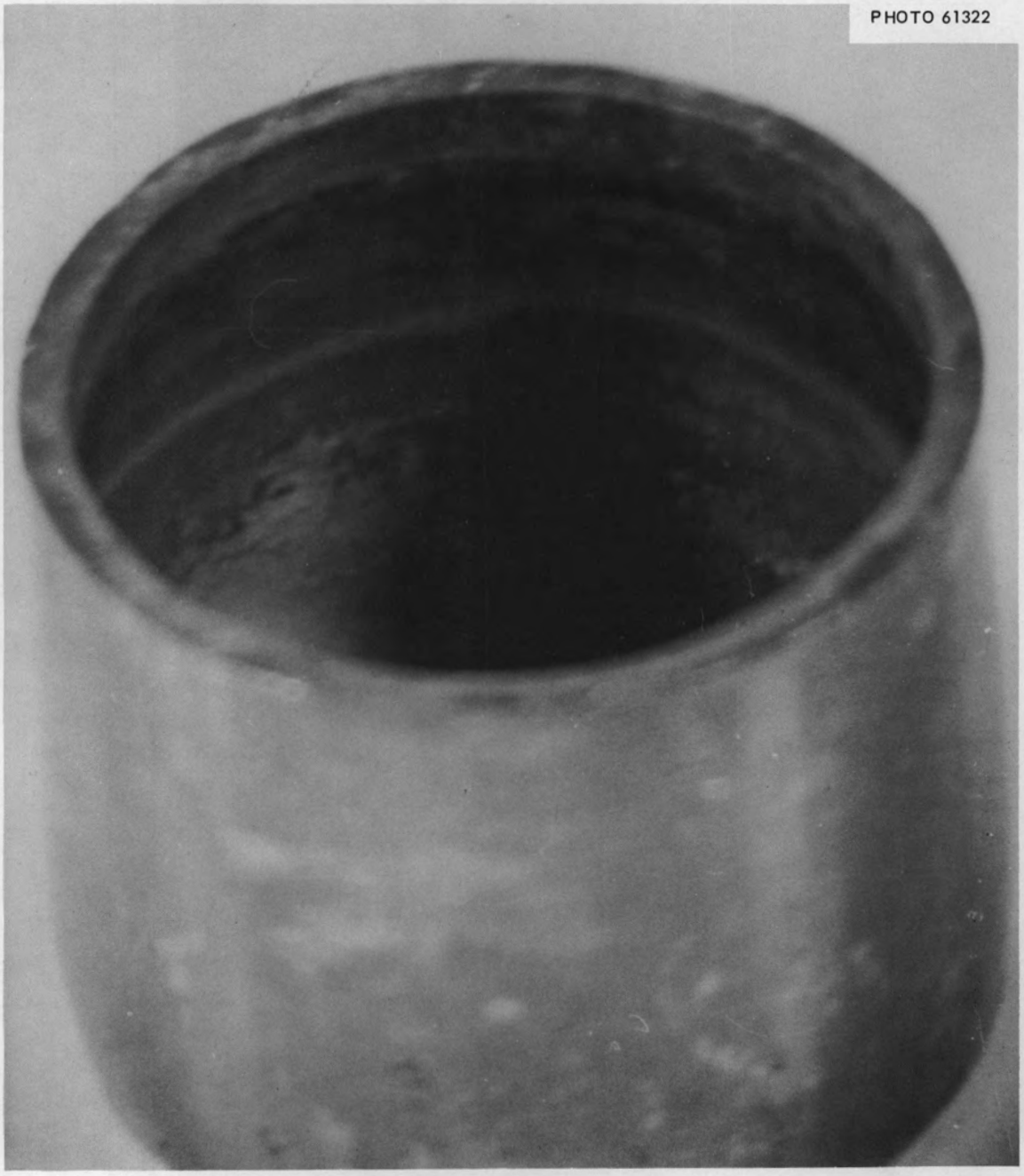

Fig. 4.12. Cesium-137 Chloride Teletherapy Source Capsule Before Sectioning.

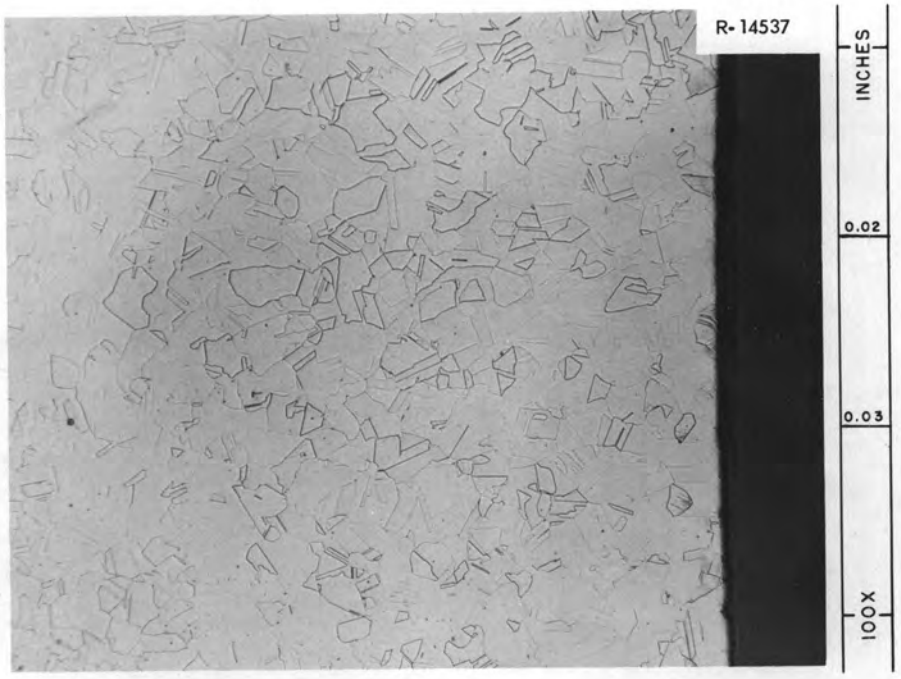

Fig. 4.13. Transverse Section of Source Wall, ID.

Fig. 4.14. Longitudinal Section of Source Wall, ID.

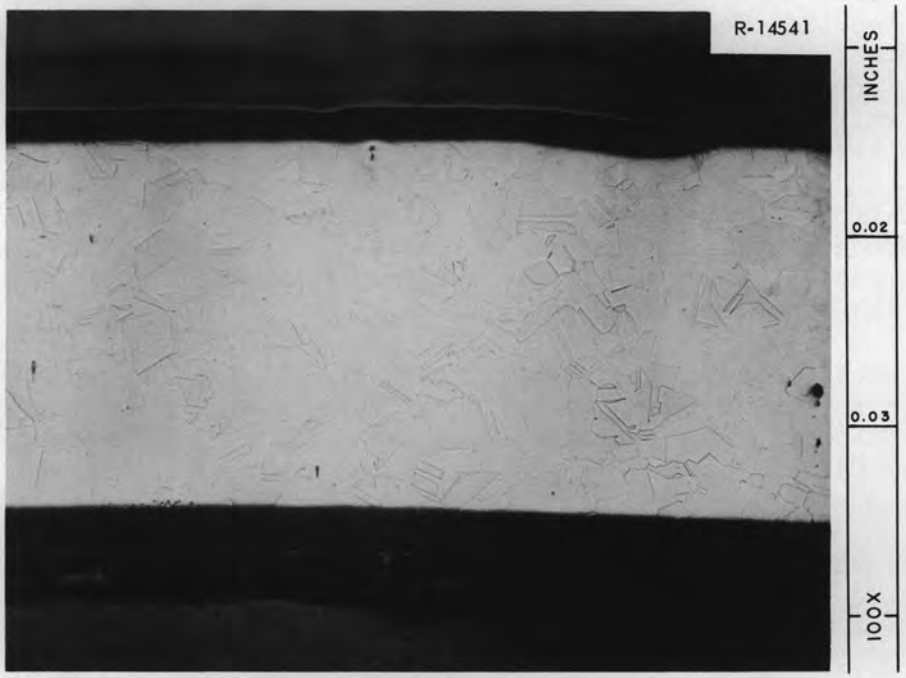

Fig. 4.15. Section of 20-mil-thick Window (Inside of Window is at Bottom).

4.1.5.3. Cobalt (T-Co-153). Inactive cobalt pellets were used as source material in this model of teletherapy source. The material was doubly encapsulated in stainless steel cylinders with welded closures. A "window thickness" of 0.040 in. was provided by 0.020-in. windows machined in one end of each capsule. The source measured 1-9/32 in. in dia by 1-7/16 in. in length and weighed ~198 g.

Three samples of this model were tested in the first series of tests. One source (1A) was subjected to a temperature of 1700°F in air for 1 hr, 500°F in air for 24 hr, and immersion in liquid nitrogen for 24 hr. No damage to the source was detected, and no leaks developed after any of these tests. In one test, after the sample had been subjected to a temperature of 2550°F in air for 1 hr, the capsule was badly oxidized and parts of the outer capsule had been burned away; however, the inner capsule did not show a leak in the vacuum leak test.

Two sources were subjected to a thermal shock test. One (1B) was heated in air to 500°F, quenched in ice water to 32°F, and transferred to air at -76°F for 15 min; the other (1C) was heated to 1700°F and quenched in a trichloroethylene-Dry Ice mixture at -76°F. Microscopic examination following these tests did not show any cracks or defects, and vacuum leak tests gave no evidence of leaks.

In structural tests, a shear force of 1000 lb for 1 hr and 10,000 lb for 1 hr dented the capsule, but close examination revealed no penetration. When tested to failure, the capsule sheared at 18,500 lb of force. A crushing force of 2000 lb for 1 hr collapsed the plug end of one source, but the unit did not leak when subjected to a vacuum leak test. In a puncture test, one source was placed window down on a hardened steel pin 1/8 in. in dia. A 600-g weight dropped onto the source from a height of 5 ft indented the window 0.050 in., but there was no penetration and the source did not leak in a vacuum leak test. In the same type test on another source, a 1182-g weight dropped from a height of 5 ft caused punctures of both the outer and inner capsules.

A second set (four) of this source model was obtained to confirm results in the first series of tests and to classify the source under the ORNL Source Capsule Classification System. There was no damage to the sources as a result of Class C temperature tests, and no leaks were observed in vacuum leak tests made after each of the temperature tests.

During Class III structural tests, some flattening of the capsule occurred (Resistance to Crushing and Impact Force Resistance tests) (Fig. 4.16) and some indentations were made (Resistance to Shear and Puncture Resistance) (Fig. 4.17); but microscopic examination showed no penetration, and vacuum leak tests did not disclose any leaks. After the External Pressure Resistance test, the ends of the capsule were slightly "dished in" and the sides were slightly bowed; but there were no cracks or breaks in the walls or welds, and the capsule did not leak.

The T-Co-153 model teletherapy source was classified as C-III.

Fig. 4.16. T-Co-153 After Class III Resistance to Crushing and Impact Force Resistance Tests.

Fig. 4.17. T-Co-153 After Class III Resistance to Shear and Puncture Resistance Tests.

4.1.5.4. Five- to Eight-Year Old O-Ring Cobalt-60 Sources. Eighteen lead O-ring ^{60}Co teletherapy sources from five to eight years old were tested to determine the effects of age.[6] The source capsules (Fig. 4.18) had five parts: body, plug, cup, and two lead O-rings. The body, constructed of an alloy with 90% W, 6% Ni, and 4% Cu, was 1.870 in. high with an OD of 1.994 in. and an ID of 1.237 in. One end of the body was threaded to hold the source in the teletherapy machine. The other end of the body had a hole 1-1/8 in. in dia for emittance of the radiation beam.

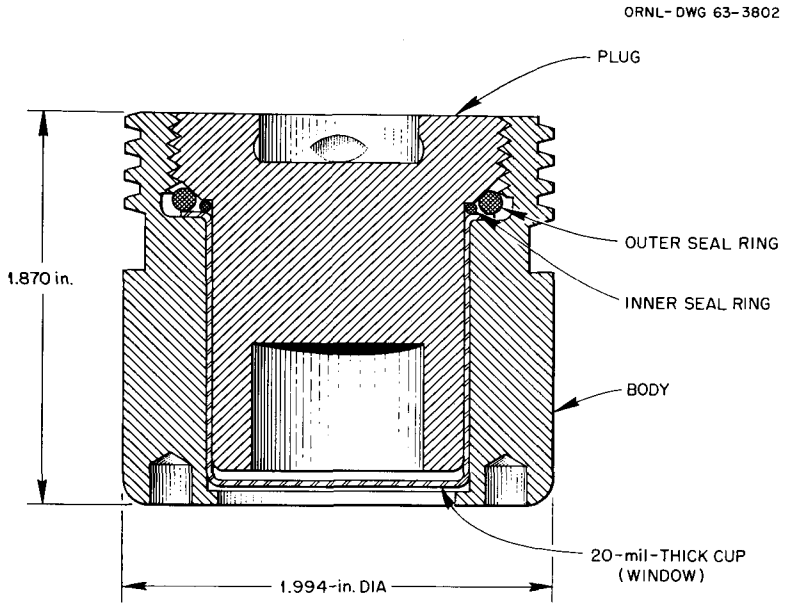

Fig. 4.18. Cobalt-60 Teletherapy Source Capsule. Plug and body of tungsten alloy (90% W, 6% Ni, and 4% Cu), O-ring seal of lead, and cup of type 305 stainless steel.

Plugs for the three types of sources were also made of the tungsten alloy. One plug was designed to hold 2-cm-dia cobalt wafers; a second could hold six 1- by 1-cm pellets in a "coverleaf"[17] array. The depths of both of these plugs could be varied. The third type plug, 0.542 in. deep, was used for 1- by 1-mm cobalt pellets. A 45° taper at the end of the plug threads formed the outer sealing surface. The outer seal ring was a 1/8-in.-dia antimony-free lead wire formed into an O-ring of 1-3/8 in. ID.

The cup was made of 0.020-in.-thick 305 stainless steel with an ID of 1.187 in. and an inner height of 1.306 in. The seamless cup had an open top with a 1.5-in.-dia lip and had been annealed at 2000°F and air cooled before and after being formed. The lip on the open top of the cup was the second, or inner, sealing surface. The seal ring was a 1/16-in.-dia antimony-free lead O-ring of 1-3/16 in. ID.

Visual inspection indicated that the capsules were not damaged. They were subjected to several leak tests which included (a) smearing with absorbent paper to determine the presence of transferable activity; (b) weighing, immersing in water at 300 psi for 1 hr, and reweighing (a gain in weight

would indicate a leak); (c) resmearing with absorbent paper to determine the presence of transferable activity; (d) placing in air at a pressure of 90 psig for 15 min, then in hot water and observing for bubble formation (a stream of bubbles would indicate a leak); (e) smearing for a third time with absorbent paper for transferable activity; and (f) immersing in ethylene glycol and decreasing the pressure to 5 in. Hg absolute. Test results (a - e) are given in Table 4.5.

Table 4.5. Cobalt-60 Teletherapy Source Test Results

Source	Test a smear,[a] dis/min	Test b			Test c smear,[a] dis/min	Test d bubbles	Test e smear,[a] dis/min
		Initial wt, g	Wt after soaking, g	Wt gain, g			
1	60	1313.85	1314.60	0.75	10	None	13,570
2	600	1345.40	1344.50	-0.90	2,300	Few	9,890
3	60	1337.60	1338.45	0.85	10	None	42,070
4	1,750	1342.65	1342.70	0.05	406,180	None	727,630
5	6,000	1346.49	1348.05	1.56	12,700	None	109,340
6	27,700	1316.40	1317.30	0.90	147,300	Many	35,550
7	12,674	1314.75	1314.20	-0.55	155,180	Many	102,000
8	250	1299.81	1300.00	0.19	b	None	105,800
9	2,000	1357.85	1358.70	0.95	19,800	None	18,430
10	8,960	1337.85	1340.00	2.15	270,140	Many	552,140
11	8,310	1351.60	1354.30	2.70	16,000	Few	377,820
12	17,500	1338.20	1340.05	1.85	8,600	Few	142,780
13	143,540	1194.10	1194.20	0.10	77,120	Many	23,810
14	203	1188.35	1191.10	2.75	155,780	c	124,850
15	5,470	1264.48	1267.30	2.82	7,140	None	141,110
16	39,420	1317.90	1317.00	-0.90	51,090	Many	22,760
17	6,330	1311.10	1311.85	0.75	310,300	None	298,420
18	970	1315.60	1317.60	2.00	99,600	Many	178,460

[a]Smears taken of total source area.
[b]Background.
[c]Small for 10 sec.

The initial smears showed transferable activity >1000 dis/min (limit at ORNL for shipping sealed sources) on the surfaces of 12 sources. When immersed in water at 300 psig, all but three sources increased in weight; when smeared again, all but three showed a surface activity >1000 dis/min. The hot-water bubble leak test was not effective for determining the leaks. The sources were then leak-tested by immersing in ethylene glycol and

decreasing the pressure above the glycol to 5 in. Hg absolute. Leaks were present in all capsules as indicated by formation of bubbles.

When disassembled, each source showed breaks in both O-ring seals with spaces of ~1/16 in. between the ends (Fig. 4.19). The seals appeared to have been pulled apart in the initial sealing process. No other damage was observed. Although all 18 sources were stored in the same container, there was no evidence of melted gaskets. All of the capsules contained a fine powder that had the appearance of cobalt oxide but was not analyzed. This powdery material was removed from five of the sources and weighed. In each case the weight of the material was <1% of the total weight of cobalt in the source. Three of these five sources contained nickel-plated cobalt, and the other two contained bare cobalt metal.

Fig. 4.19. Disassembled Teletherapy Source Showing Separation of Lead Gasket.

Four of the sources were reassembled without cobalt and subjected to structural tests in order to determine the maximum physical conditions which a source of this type could withstand. The first unit was dropped onto a 0.25-in.-dia rod with the 20-mil-thick window of the source striking the end of the rod. The first drop was from 6 in.; distances for subsequent drops were increased by 6-in. increments up to 2 ft. At this height the window ruptured. The second and third sources were dropped initially from a height of 2 ft, and in both cases the window ruptured (Fig. 4.20). The fourth capsule was placed on its side in a 50-ton press. Force was applied until the body cracked at a total applied force of 84,000 lb (Fig. 4.21).

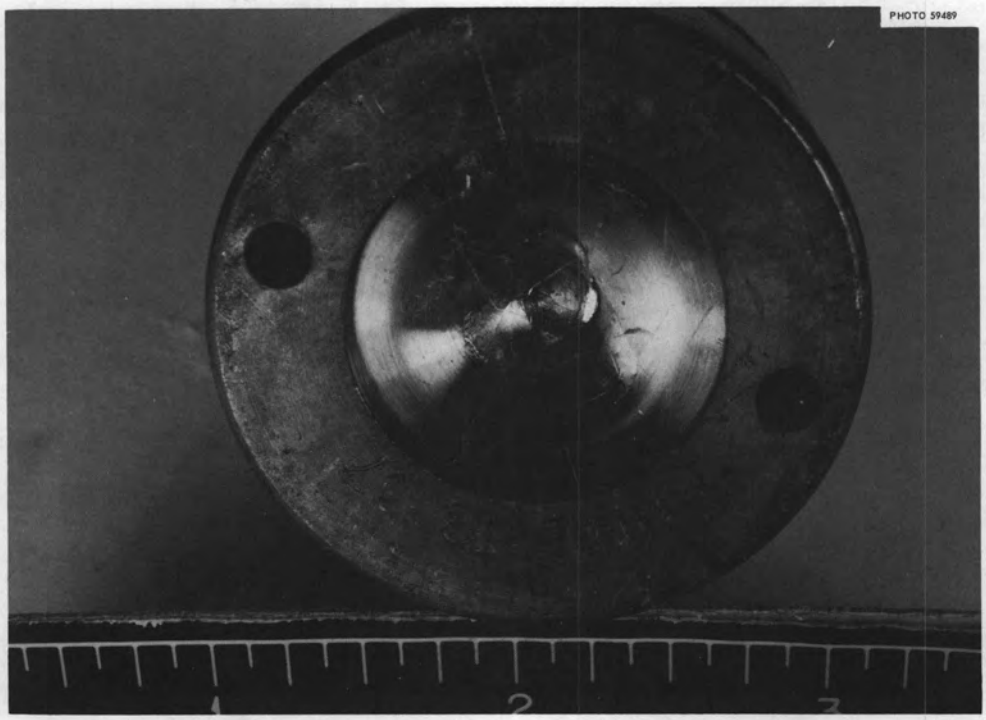

Fig. 4.20. Teletherapy Source After It Was Dropped 2 ft onto 0.25-in.-dia Rod.

Fig. 4.21. Teletherapy Source Cracked by 84,000-lb Force. Note crack through "L" in ORNL.

4.2. Radiography Sources

4.2.1. Cobalt

4.2.1.1. R-Co-2. One radioactive and three inactive cobalt sources were received for testing. Each source was an 0.800-in.-long cylinder with rounded ends (0.352 in. in dia) and weighed 6.8 g. The welded sources were doubly encapsulated in stainless steel.

A smear of the entire surface of the radioactive source with filter paper showed 220 dis/min. After being weighed, the source was placed in a pressure vessel under 300 psig water pressure for 64 hr. During this period, the pressure was decreased to 210 psig. The source showed no leaks. The source was then placed in a pressure vessel under 90 psig air for 1 hr; then it was placed in hot (~200°F) water and observed for bubbles for 5 min. None were detected. A dye penetrant revealed no surface cracks in the source welds. The source was then vibrated with a standard 60-cycle shaker for 1 hr; no visible damage was detected. The source was again placed in a pressure chamber at 90 psig air and subjected to a vacuum leak test. The source leaked profusely in the weld area. After the outer capsule was removed and X rayed, the crack in the weld could be plainly seen. These leaks must have been in the weld when the source was received.

The inner source capsule was then cleaned and smeared; 2500 dis/min were found. The inner capsule was placed in a pressure chamber at 90-psig air for 1 hr and then subjected to a vacuum leak test. The capsule leaked profusely at the weld. The source was then placed in hot (~200°F) water for 5 min. No leaks were detected. The source was again subjected to a vacuum leak test and again the leaks were easily detected.

None of the three inactive sources leaked when subjected to the vacuum leak test. The first source (A) was X rayed for weld inspection. The X ray showed a crack in the weld but it could not be determined if the crack penetrated the weld. The source was then subjected to a series of crushing tests using up to 22,300 lb of force. The capsule was flattened to 0.215 in., but the source did not leak. An X ray of the second source (B) showed the weld to be perfect. The third source (C) was X rayed and cracks were seen in the interior of the weld; however, it could not be determined if these cracks extended through the weld. When the source was subjected to a shear test, the inner and outer capsules sheared at 9360 lb.

4.2.1.2. R-Co-9. Eleven 0.680-in.-long sources, with a 0.264-in. dia at one end and a 0.203-in. dia at the other end, were obtained for testing. The sources were doubly encapsulated in welded stainless steel and weighed ~2 g. The first source tested contained radioactive cobalt; the other ten sources contained inactive material. Figure 4.22 shows R-Co-9-3A after the impact test; Fig. 4.23 shows R-Co-9-3B after the shear test.

These sources were classified as C-III after being subjected to the tests listed in Table 4.6.

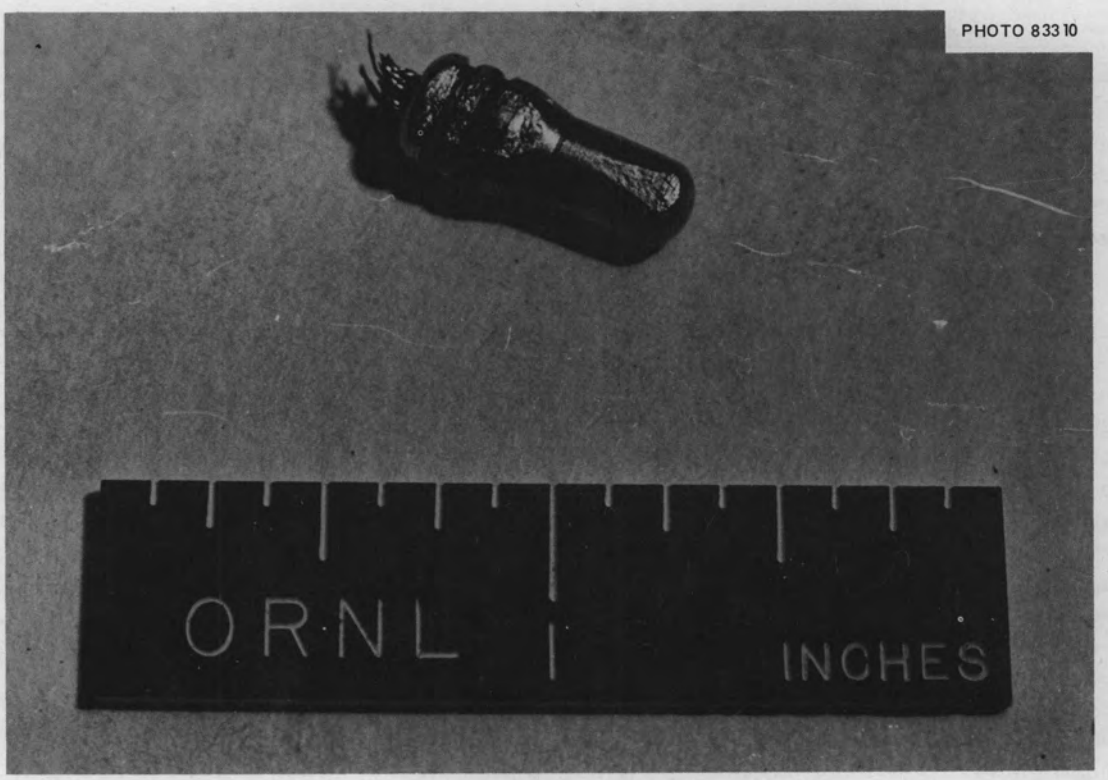

Fig. 4.22. R-Co-9-3A After the Impact Force Resistance Test.

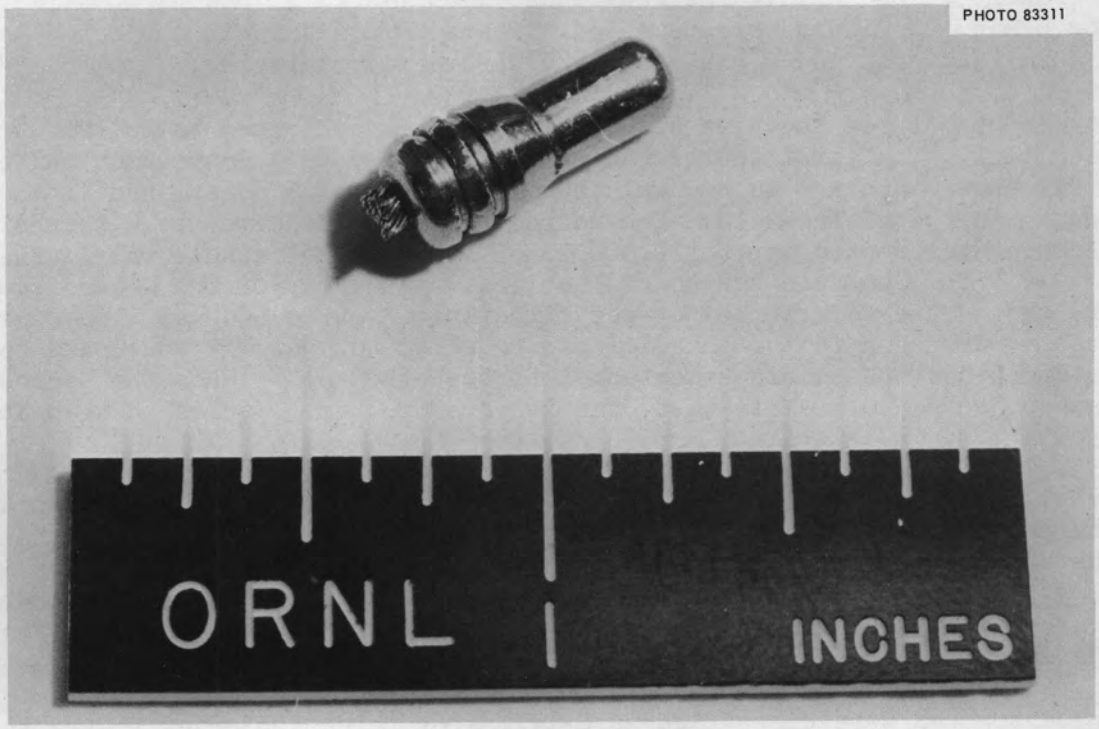

Fig. 4.23. R-Co-9-3B After the Resistance to Shear Test.

Table 4.6. Test Results of R-Co-9 Sources

Source	Type of test	Conditions	Results
A	Smear	Filter paper	110 dis/min
	Vacuum leak	—	Leaked
	External pressure leak	300 psig for 1 hr	No wt gain
	External pressure hot-water leak	90 psig for 1 hr, then to 200°F	No leaks
1A	Crushing	13,400 lb	No leaks
1B	External pressure	22,000 psig for 1 hr	No leaks
1C	Not tested		
2A	Temperature resistance	1700°F for 1 hr in air, -320°F for 24 hr	No leaks
	Operating temperature	500°F for 24 hr in air	No leaks
	Thermal shock	500 to 32 to -76°F for 15 min	No leaks
	Maximum temperature	2550°F for 1 hr in air	Cracks
2B	Impact	12 lb from 5 ft	No leaks
	Thermal shock	1700 to -76°F	No leaks
2C	Crushing	2000 lb for 1 hr	No leaks
	Shear	1000 lb for 1 hr	No leaks
	Puncture resistance	35 g from 5 ft	No leaks
3A	External pressure	1000 lb/in.^{2} for 15 min	No leaks
	Crushing	2000 lb for 1 hr	No leaks
	Impact	12 lb from 5 ft	No leaks
3B	Shear	1000 lb for 1 hr	No leaks
	Puncture resistance	10 g from 5 ft	No leaks
3C	Thermal shock	500 to 32 to -76°F for 15 min	No leaks
	Maximum temperature	1700°F for 1 hr in air	No leaks
3D	Operating temperature	-320°F for 24 hr	No leaks
	Operating temperature	500°F for 24 hr	No leaks

4.2.1.3. R-Co-70 (R-Co-87). Two 2-curie ^{60}Co sources were sent to ORNL for burial. The 0.470-in.-dia by 0.950-in.-long sources were singly encapsulated in stainless steel and closed with threaded plugs. The capsules were sawed in half, ^{60}Co was removed, and the capsules were cleaned to ~100 mr/hr. After further decontamination in an ultrasonic cleaner, the capsules were sectioned and examined. No deterioration or degradation of the weld areas or the capsules walls was detected by microscopic examination. This examination also disclosed that the threaded plugs were sealed with a resinous material rather than solder. This type of source is no longer being manufactured.

4.2.1.4. R-Co-81. Twelve welded sources, singly encapsulated in stainless steel with dimensions of 0.950-in. length, 0.470-in. dia, and 0.025-in.-thick walls, were obtained for testing. These sources were classified as C-III after being subjected to the tests listed in Table 4.7.

Figure 4.24 shows R-Co-81-2D after the impact test.

Fig. 4.24. R-Co-81-2D After the Impact Force Resistance Test.

Table 4.7. Test Results of R-Co-81 Sources

Source	Type of test	Conditions	Results
A	Impact	6 lb from 12 ft	No leaks
B	Operating temperature	100°F for 24 hr in air	No leaks
	Maximum temperature	1700°F for 1 hr in air	No leaks
	Thermal shock	1700°F to -320°F	No leaks
C	Puncture resistance	15 ft	No leaks
D	Shear	7488 lb	Failed
E	Impact	200 lb from 3 ft	No leaks
	External pressure	22,000 psig for 1 hr	No leaks
F	Crushing force	100 to 5000 lb	No leaks
1A	Maximum temperature	1700°F for 1 hr in air	No leaks
	Operating temperature	1000°F for 24 hr in air	No leaks
	Thermal shock	500 to 32°F, then to -76°F for 15 min	No leaks
	Maximum temperature	2550°F for 1 hr in air	Severe oxidation
1B	Impact	12 lb from 5 ft	Leaked
	Shear	4200 lb	Failed
1C	Crushing force	2000 lb for 1 hr	No leaks
2A	Shear	1000 lb for 1 hr	No leaks
	Puncture resistance	0.55 lb from 5 ft	No leaks
	Thermal shock	1700 to -76°F	No leaks
2B	External pressure	1000 psig for 1 hr	No leaks
	Puncture resistance	0.132 lb from 5 ft	No leaks
	Crushing force	2000 lb for 1 hr	No leaks
	Shear	1000 lb for 1 hr	No leaks
	Thermal shock	500 to 32°F, then to -76°F for 15 min	No leaks
	Maximum temperature	1700°F for 1 hr in air	Slight discoloration
2C	Operating temperature	-320°F for 24 hr	No leaks
	Operating temperature	500°F in air for 24 hr	No leaks
2D	Impact	12 lb from 5 ft	No leaks

4.2.1.5. R-Co-109. Three 6-mm-dia by 6-mm-long sources with aluminum capsules were obtained for testing (Fig. 4.25). The tests performed on each source and the results are given in Table 4.8.

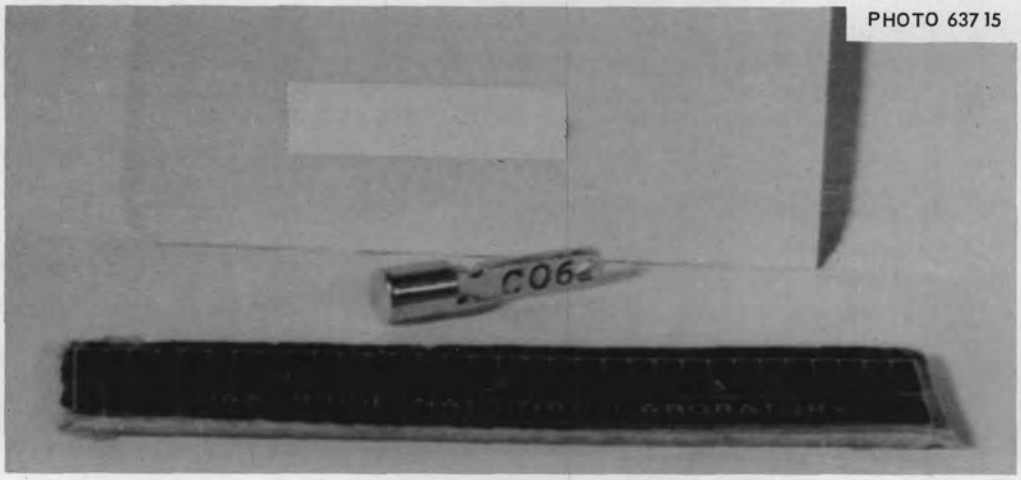

Fig. 4.25. R-Co-109 as Received.

Table 4.8. Test Results of R-Co-109 Sources

Source	Type of test	Conditions	Results
A	Temperature resistance	750°F for 1 hr, then to -40°F for 24 hr	No leaks
	Puncture resistance	8 ft onto 1/8-in.-dia pin	No leaks
B	Operating temperature	212°F for 24 hr	No leaks
C	Crushing	200 lb for 1 hr	No leaks
	Crushing	2000 lb	No leaks

4.2.1.6. R-Co-110. Three 12-mm-dia by 12-mm-long sources were obtained for testing (Fig. 4.26). The sources were encapsulated in aluminum and had a crimped seal. When the first source (A) underwent a vacuum leak test, the crimped seal leaked. The seal of the second source (B) also leaked. This source was immersed in a dye penetrant, a vacuum was applied for 2 min, and the source was left in the liquid for 1/2 hr. After the dye was removed from the surface, the source was opened and dye penetrant was found inside. The third source (C) also leaked. No further tests were conducted on these sources since by definition they were not sealed sources.

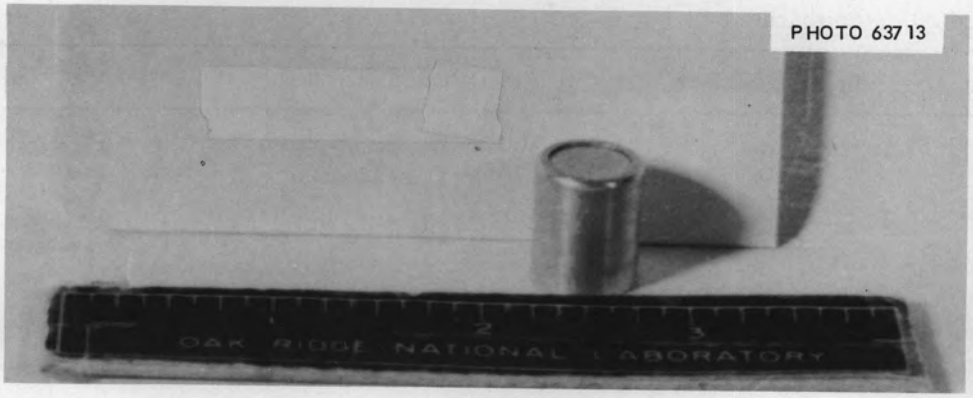

Fig. 4.26. R-Co-110 as Received.

4.2.1.7. R-Co-154. Seven inactive sources of this model were first acquired for testing (Fig. 4.27). This cylindrical source had a diameter of 0.530 in., was 1.8 in. long, and weighed 32.3 g. The capsule was double stainless steel with welded closures. Results of tests on this group of sources are tabulated in Table 4.9.

Fig. 4.27. R-Co-154 as Received.

Table 4.9. Test Results of R-Co-154 Sources (First Series)

Source	Type of test	Conditions	Results
A	Maximum temperature	1700°F for 1 hr in air	No leaks
	Operating temperature	500°F for 24 hr, -320°F for 24 hr	No leaks

Table 4.9. continued

Source	Type of test	Conditions	Results
A	Thermal shock	500°F to 32°F then to -76°F for 15 min	No leaks
	Maximum temperature	2550°F for 1 hr	Outer capsule burned off, inner capsule leaked
B	Shear	1000 lb for 1 hr	No leaks, slight indentations
	Crushing	1000 lb for 1 hr	No leaks
	Puncture	400 g from 5 ft onto capsule on 1/8-dia pin	No leaks, end of capsule indented 0.05 in.
	Thermal shock	1700°F to -76°F	No leaks
C	Puncture	100 g from 5 ft onto capsule on 1/8-dia pin	No leaks
	Impact	12 lb from 5 ft	No leaks, flattened to 0.49 in.

A second set of four sources was obtained for verification of results and for classification in the ORNL Source Capsule Classification System. The results of these tests are given in Table 4.10.

Table 4.10. Test Results of R-Co-154 Sources (Second Series)

Source	Class	Type of test	Results
1A	III	External Pressure Resistance	No leaks, window end slightly caved in
	III	Resistance to Crushing	No leaks
	III	Impact Force Resistance	Some flattening, no leaks
1B	III	Resistance to Shear	No leaks
	III	Puncture Resistance	No leaks
1C	C	Thermal Shock Resistance	No leaks
	C	Maximum Temperature Resistance	No leaks
1D	C	Operating Temperature Resistance	
		Low	No leaks
		High	No leaks

Figure 4.28 shows R-Co-154-1B after the Class III Resistance to Shear Test.

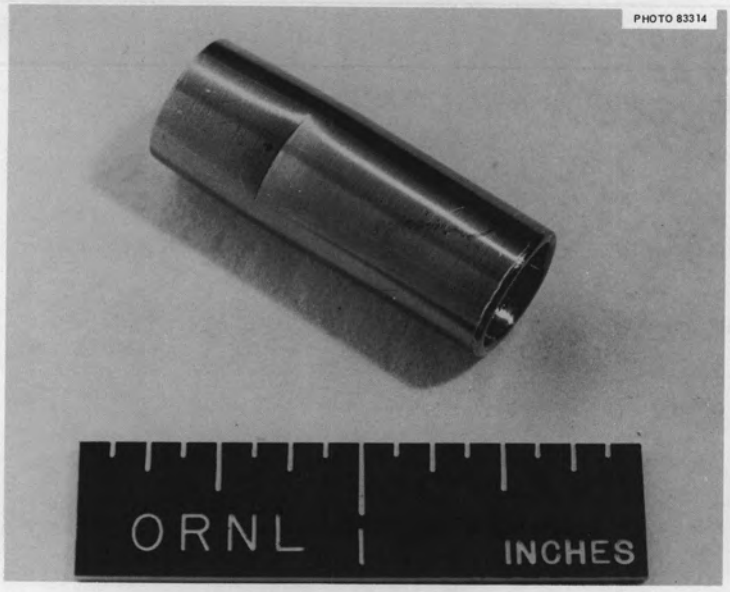

Fig. 4.28. R-Co-154-1B After the Class III Resistance to Shear Test.

R-Co-154 was classified as C-III.

4.2.1.8. R-Co-155. Eight inactive samples of R-Co-155 were obtained for testing (Fig. 4.29). This source is a welded stainless steel cylinder (0.250-in. dia by 0.627-in. length). Results of tests performed on these sources are detailed in Table 4.11.

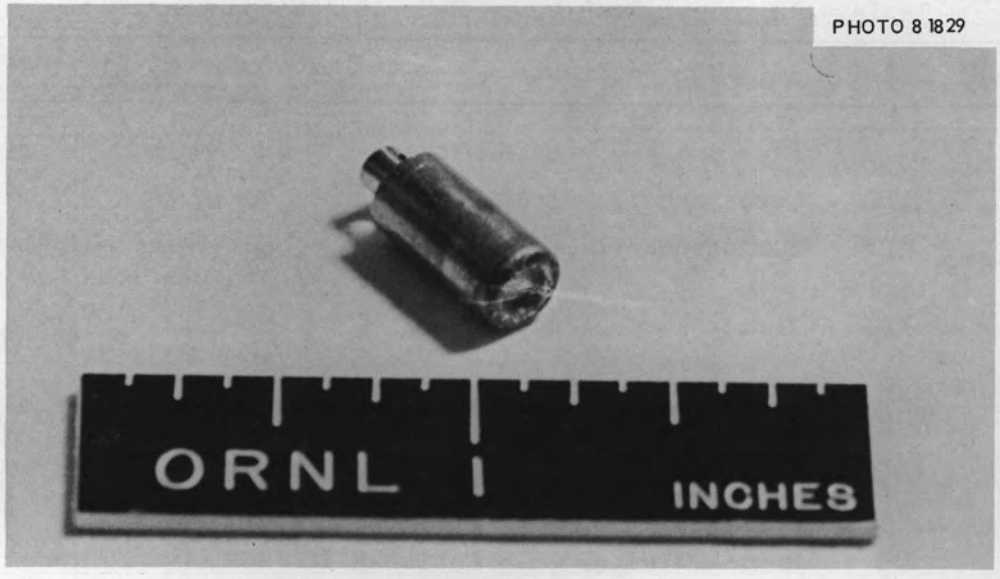

Fig. 4.29. R-Co-155 as Received.

Table 4.11. Test Results on R-Co-155 (First Series)

Source	Type of test	Conditions	Results
A	Maximum temperature	1700°F for 1 hr	No leaks
	Operating temperature	500°F for 24 hr	No leaks
	Operating temperature	-320°F for 24 hr	No leaks
	Thermal shock	From 500 to 32 to -76°F for 15 min	No leaks
	Maximum temperature	2550°F for 1 hr	Badly oxidized, leaked
B	Crushing	2000 lb for 1 hr	No leaks
	Shear	1000 lb for 1 hr	No leaks
	Thermal shock	1700°F to -76°F	No leaks
C	Puncture	35 g from 5 ft onto capsule on 1/8-in.-dia pin	No leaks
	Impact	12 lb from 5 ft	No leaks, flattened to 0.211 in.

Later in the program, five more sources of this model were used to reaffirm earlier test results and to classify the source in the ORNL classification system. Table 4.12 gives these results.

Table 4.12. Test Results on R-Co-155 (Second Series)

Source	Class	Type of test	Results
1A	V	External Pressure Resistance	No leaks
	III	Resistance to Crushing	No leaks
	III	Resistance to Shear	No leaks, slight indentations
	III	Impact Force Resistance	No leaks, flattened to 0.213 in.
1B	C	Operating Temperature Resistance	
		Low	No leaks
		High	No leaks
1C	C	Thermal Shock Resistance	No leaks
	C	Maximum Temperature Resistance	No leaks

Sources 1D and 1E were not tested.

Model R-Co-155 was classified as C-III.

4.2.1.9. R-Co-156. A total of eight inactive sources of this type were obtained for testing. The source (0.25-in. dia, 7/8-in. length) was doubly encapsulated in stainless steel and weighed ~10 g. A 0.375-in. flat-to-flat hexagonal nut was welded to one end of the source, and a 0.25-in. bolt was screwed and welded into this piece. Three samples were tested in the first series of tests (results given in Table 4.13); at a later date, five more samples were acquired to verify the results of the previous tests and to classify the source in the ORNL classification system (see Table 4.14). R-Co-156 was classified as C-III. Figure 4.30 shows R-Co-156-1C after the Class III Maximum Temperature Resistance test.

Table 4.13. Test Results on R-Co-156 (First Series)

Source	Type of test	Conditions	Results
A	Maximum temperature	1700°F for 1 hr in air	No leaks
	Operating temperature	500°F for 24 hr	No leaks
	Operating temperature	-320°F for 24 hr	No leaks
	Thermal shock	500°F to 32°F then to -76°F for 15 min	No leaks
	Maximum temperature	2550°F for 1 hr	Both inner and outer capsules destroyed
B	Shear	1000 lb for 1 hr	Source bent ~5° from vertical; no leaks
	Crushing force	2000 lb for 1 hr	No leaks
	Thermal shock	1700°F to -76°F for 15 min	No leaks
C	Puncture	120 g dropped from 5 ft onto source on 1/8-in.-dia pin	No leaks
	Impact	12 lb from 5 ft	Flattened source from 0.373 to 0.355 in.; no leaks
	External pressure	22,000 psig for 1 hr	No leaks

Table 4.14. Test Results on R-Co-156 (Second Series)

Source	Class	Type of test	Results
1A	V	External Pressure Resistance	No leaks
	III	Resistance to Crushing	No leaks
	III	Puncture Resistance	No leaks
	III	Impact Force Resistance	Flattened to 0.22 in.; no leaks
1B	III	Resistance to Shear	No leaks
	C	Operating Temperature Resistance	
		High	No leaks
		Low	No leaks
1C	C	Thermal Shock Resistance	No leaks
	C	Maximum Temperature Resistance	No leaks

Sources 1D and 1E not tested.

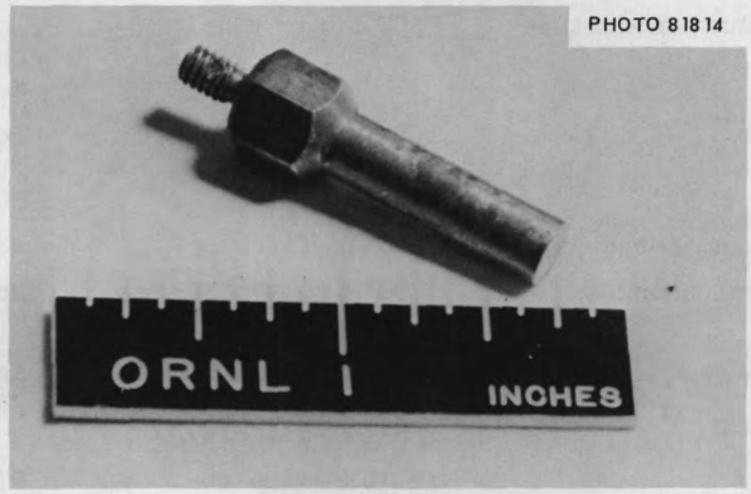

Fig. 4.30. R-Co-156-1C After the Class III Maximum Temperature Resistance Test.

4.2.1.10. R-Co-200. Four inactive samples of this type were obtained for classification in the ORNL classification system. The source was a nominal cylinder with hemispherical ends (0.471-in. dia in the source area and 0.534-in. dia in the weld area) encapsulated in stainless steel. The unit was 0.93 in. long, had a cable attached to one end, and weighed ~16 g. Table 4.15 summarizes test results for this source.

Table 4.15. Test Results on R-Co-200

Source	Class	Type of test	Results
A	III	External Pressure Resistance	No leaks
	III	Resistance to Crushing	No leaks
	III	Impact Force Resistance	No leaks
	D	Maximum Temperature Resistance	Burned capsule leaked
B	III	Resistance to Shear	No leaks
	III	Puncture Resistance	Slightly indented, no leaks
	C	Maximum Temperature Resistance	No leaks
C	C	Thermal Shock Resistance	Leaked[a]
D	C	Operating Temperature Resistance	
		Low	No leaks
		High	No leaks
	C	Thermal Shock Resistance	No leaks

[a]Microscopic examination revealed small hole in weld which appeared to be caused by included material which was dislodged during test.

R-Co-200 was classified as C-III.

4.2.2. Cesium

4.2.2.1. R-Cs-55. One ~5-curie ^{137}CsCl source, doubly encapsulated in stainless steel, was obtained for testing. The unit was 1.37 in. long and 0.329 in. in dia. When the source was subjected to a vacuum leak test, small bubbles were emitted from two points on the weld. After the outer capsule was removed, a vacuum leak test of the inner capsule revealed three small leaks on this weld. A smear of the outer capsule read ~10 mr/hr.

4.2.2.2. R-Cs-56. One ~10-curie ^{137}Cs source was obtained for testing. The unit (0.907 in. in length by 0.252 in. in dia) was doubly encapsulated in stainless steel. No leaks were detected by a vacuum leak test. A smear of the outer capsule read 5 mr/hr; a smear of the inner capsule read 45 mr/hr. When the inner capsule was subjected to a vacuum leak test, the entire surface of the weld area appeared to leak.

4.2.2.3. R-Cs-68. Ten ~42-g sources in stainless steel cylinders, 0.880 in. high by 0.738 in. in dia, were used for testing. Table 4.16 summarizes the results of the testing program on this type of source.

Figure 4.31 shows R-Cs-68-2C after the Class C Maximum Temperature Resistance test (A) compared with the received source (B). R-Cs-68 was classified as C-III.

Table 4.16. Test Results on R-Cs-68 Sources

Source	Type of test	Conditions	Results
A	Maximum temperature	1700°F for 1 hr in air	No leaks
	Maximum temperature	2550°F for 10 min in air	No leaks
1A	Maximum temperature	1700°F for 1 hr in air	No leaks
	Operating temperature	750°F for 24 hr; -320°F for 24 hr	No leaks
	Thermal shock	500°F for 1 hr to 32°F, then to -76°F for 15 min	No leaks
	Maximum temperature	2550°F for 1 hr	Leaked
1B	Impact	12 lb from 5 ft	No leaks
	Crushing	20,000 lb for 1 hr	Ruptured
1C	Crushing	2000 lb for 1 hr	No leaks
	Puncture	125 g from 5 ft	No leaks
1D	Shear	1000 lb for 1 hr	No leaks
	Puncture	252 g from 5 ft	No leaks
	Puncture	504 g from 5 ft	Small leak
	Shear	24,000 lb	Failed
Sources 1E and 1F not tested			
2A	External pressure	1000 psi for 1 hr	No leaks
	Puncture	100 g from 5 ft	No leaks
	Crushing	2000 lb for 1 hr	No leaks
	Shear	1000 lb for 1 hr	No leaks
2B	Operating temperature	-320°F for 24 hr	No leaks
	Operating temperature	500°F for 24 hr in air	No leaks
	Impact	12 lb from 5 ft	No leaks
2C	Thermal shock	500 to 32 to -76°F for 15 min	No leaks
	Maximum temperature	1700°F for 1 hr in air	No leaks

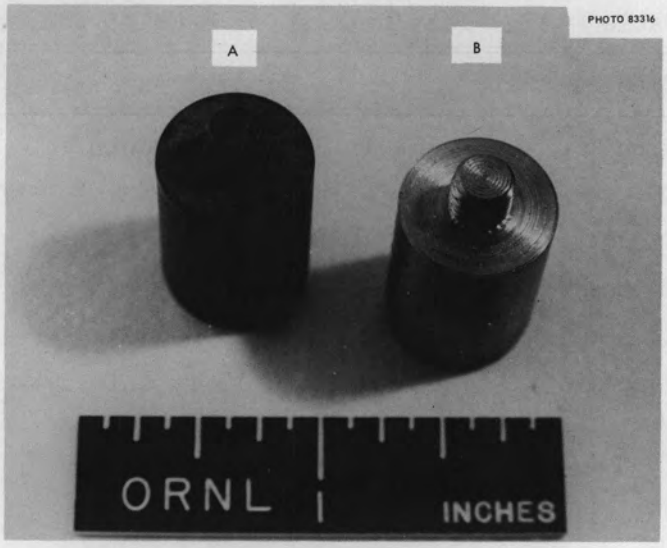

Fig. 4.31. R-Cs-68-2C After Class C Maximum Temperature Resistance Test (A) Compared with R-Cs-68 as Received (B).

4.2.2.4. R-Cs-83. Fourteen sources were obtained for testing. The sources were doubly encapsulated in stainless steel and had dimensions of 0.907-in. length, 0.252-in. dia, and 0.020-in.-thick walls (Fig. 4.32). Both inner and outer capsules were sealed by Heliarc welding. The capsules normally contained 4-mm-dia ^{137}Cs pellets; however, inactive CsCl pellets were used for testing. Tests results are given in Table 4.17. R-Cs-83 was classified as C-III.

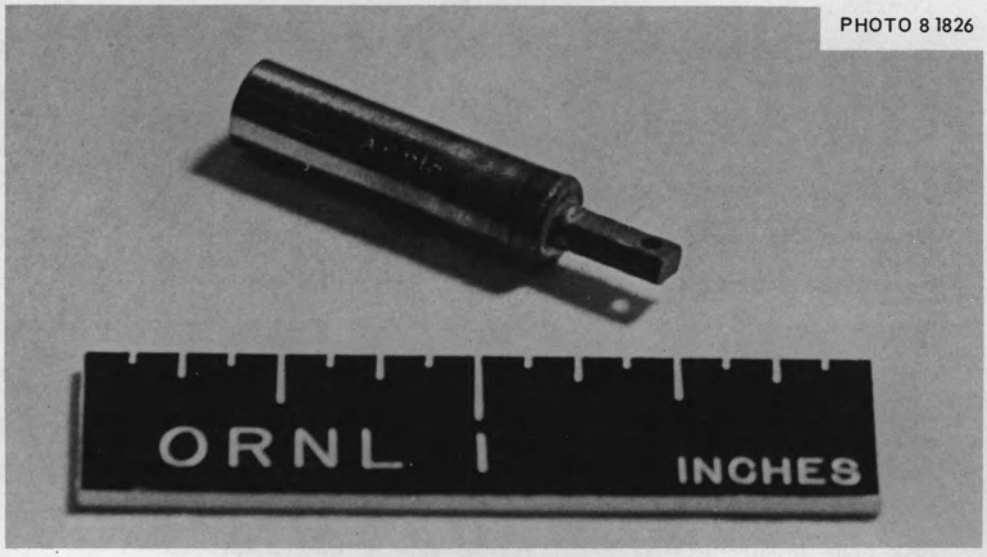

Fig. 4.32. R-Cs-83 as Received.

Table 4.17. Test Results on R-Cs-83 Sources

Source	Type of test	Conditions	Results
A	Corrosion	In H_2O for 1 month	No leaks
	Impact	6 lb from 12 ft	No leaks
B	Operating temperature	1000°F for 24 hr in air	No leaks
	Maximum temperature	1700°F for 1 hr in air	No leaks
	Thermal shock	1700°F to -320°F	No leaks
C	Puncture	Dropped 15 ft onto 1/8-in.-dia pin	No leaks
Sources D and E not tested			
F	Shear	7488 lb	Failed
G	Internal pressure	>9000 psig	No leaks
1A	Maximum temperature	1700°F for 1 hr in air	No leaks
	Operating temperature	1000°F for 24 hr in air	No leaks
	Operating temperature	-320°F for 24 hr	No leaks
	Thermal shock	500 to 32°F, then to -76°F for 15 min	No leaks
	Crushing force	2000 lb for 1 hr	No leaks
	Maximum temperature	2550°F for 1 hr in air	Leaked
1B	Impact	12 lb from 5 ft	No leaks
	Thermal shock	1700 to -76°F	No leaks
	External pressure	22,000 lb for 1 hr	No leaks
1C	Shear	1000 lb for 1 hr	No leaks
	Puncture resistance	25 g from 5 ft	No leaks
	Shear	4000 lb	Failed
2A	External pressure	1000 psig for 1 hr	No leaks
	Crushing force	2000 lb for 1 hr	No leaks
2B	Shear	1000 lb for 1 hr	No leaks
	Operating temperature	-320°F for 24 hr	No leaks
	Operating temperature	500°F for 24 hr in air	No leaks
	Thermal shock	500 to 32°F, then to -76°F for 15 min	No leaks
	Maximum temperature	1700°F for 1 hr in air	No leaks
2C	Impact	12 lb from 5 ft	No leaks
2D	Puncture resistance	16 g from 5 ft	No leaks

4.2.2.5. R-Cs-84. Thirteen 1.75-in.-long by 0.490-in.-dia sources doubly encapsulated in stainless steel were obtained for testing. Both inner and outer capsules were sealed by Heliarc welding. The sources were designed to contain 1-cm-dia ^{137}Cs pellets; however, inactive CsCl was used for testing. These sources were classified as B-III after being subjected to the tests listed in Table 4.18.

Table 4.18. Test Results of R-Cs-84 Sources

Source	Type of test	Conditions	Results
A	Shear	7488 lb	Failed
B	Operating temperature	500°F for 24 hr	No leaks
C	Puncture	15 ft onto 1/8-in.-dia pin	No leaks
	Impact	6 lb from 12 ft	No leaks
D	Corrosion	In H_2O for 1 month	No leaks
	Impact	200 lb from 3 ft	No leaks
E	External pressure	22,000 psig for 1 hr	No leaks
F	Operating temperature	1000°F for 24 hr in air	No leaks
	Maximum temperature	1700°F for 1 hr in air	Leaked
1A	Maximum temperature	1700°F for 1 hr in air	Capsules ruptured
1B	Maximum temperature	1000°F for 1 hr in air	No leaks
	Operating temperature	~-100°F (Dry Ice) for 24 hr	No leaks
	Operating temperature	212°F for 24 hr	No leaks
	Thermal shock	212 to 32°F	No leaks
	Impact	12 lb from 5 ft	No leaks
	Crushing	2000 lb for 1 hr	No leaks
1C	Shear	1000 lb for 1 hr	No leaks
	Puncture	180 g from 5 ft	No leaks
2A	External pressure	1000 psig for 1 hr	Non-sustained bubbles[a]
	Puncture	95 g from 5 ft	No leaks
	Crushing	2000 lb for 1 hr	No leaks
	Shear	1000 lb for 1 hr	No leaks
2B	Operating temperature	-40°F for 24 hr in air	No leaks
	Operating temperature	212°F for 24 hr	No leaks
	Maximum temperature	750°F for 1 hr in air	No leaks
	Thermal shock	212 to 0°F, then to -76°F for 15 min	No leaks
Source 2C not tested			
2D	Impact	12 lb from 5 ft	No leaks

[a]Interpreted as air trapped on surfaces of the weld area.

4.2.2.6. R-Cs-96. A 10-curie ^{137}Cs source doubly encapsulated in stainless steel with outer dimensions of 1.37-in. length by 0.329-in. dia was obtained. No leaks were detected during the vacuum leak test. The outer capsule was removed and the inner capsule was leak tested. Very small leaks were found at two points on the weld.

4.2.2.7. R-Cs-101. Two 34-g sources, 0.550 in. in dia by 1.25 in. high, were obtained for testing. Each source contained 1 μc of ^{137}Cs. The tests performed on each source and the results are given in Table 4.19.

Table 4.19. Test Results of R-Cs-101 Sources

Source	Type of test	Conditions	Results
A	Impact	12 lb from 5 ft	No leaks
	Impact	15 lb from 8 ft	No leaks
B	Crushing	2000 lb for 1 hr	No leaks
	Puncture resistance	408 g from 5 ft	No leaks
	Crushing	20,000 lb for 30 min	No leaks
	Crushing	50,000 lb for 30 min	No leaks

4.2.2.8. R-Cs-157. Eight inactive sources of this type were obtained for testing (three for the first series, five for the second). The cylindrical source (0.5-in. dia by 1.94-in. length) was doubly encapsulated in stainless steel with a welded closure and an eyelet in one end (Fig. 4.33). Table 4.20 gives the test results on the first three sources received.

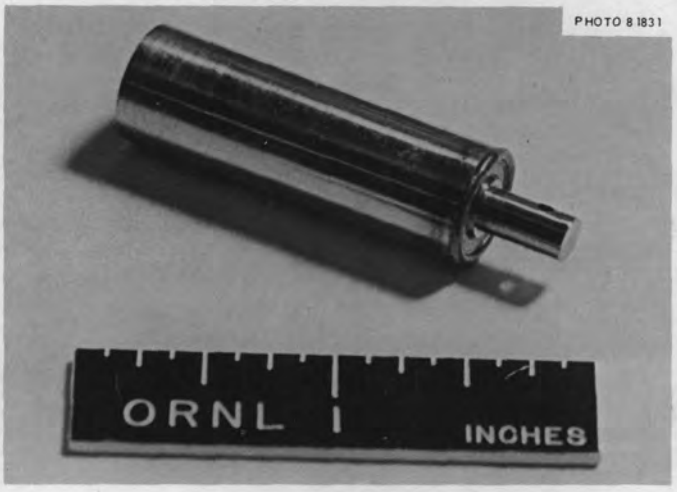

Fig. 4.33. R-Cs-157 as Received.

Table 4.20. Test Results on R-Cs-157 (First Series)

Source	Type of test	Conditions	Results
A	Maximum temperature	1700°F for 1 hr in air	No leaks
	Operating temperature	500°F for 24 hr	No leaks
	Operating temperature	-320°F for 24 hr	No leaks
	Thermal shock	500°F to 32°F, then to -76°F for 15 min	No leaks
	Maximum temperature	2550°F for 1 hr	Badly oxidized, weld and edge of end window cracked
B	Shear	1000 lb for 1 hr	No leaks
	Crushing	2000 lb for 1 hr	No leaks
	Puncture	330 g from 5 ft onto 1/8-in.-dia pin	Indented window 0.048 in., no leaks
	Thermal shock	1700°F to -56°F	No leaks
	External pressure	10,000 psig for 1 hr	Walls buckled, no leaks
C	Puncture	160 g from 5 ft	Indented window 0.038 in., no leaks
	Impact	12 lb from 5 ft	Leaked[a]

[a]Flattened to 0.477 in., sheared where capsule extended beyond impact surface.

Results of the second series of tests to classify R-Cs-157 in the ORNL classification system are given in Table 4.21.

Table 4.21. Test Results on R-Cs-157 (Second Series)

Source	Class	Type of test	Result
1A	V	External Pressure Resistance	End window dished in and cracked around edges; leaked
1B	II	Puncture Resistance	No leaks
	II	Resistance to Crushing	No leaks
	II	Resistance to Shear	No leaks
1C	II	Impact Force Resistance	Capsule sheared; leaked
1D	C	Operating Temperature Resistance	
		Low	No leaks
		High	No leaks
	C	Thermal Shock Resistance	No leaks
	C	Maximum Temperature Resistance	No leaks
1E	I	Impact Force Resistance	No leaks

This source was classified as C-I; however, it was determined during testing that the capsules contained no inactive material as specified. Had this material been in place to absorb the shock of the impact test, it is possible that R-Cs-157 would have classified as C-III or C-II. Figure 4.34 shows R-Cs-157-1B after the Class II Puncture Resistance test.

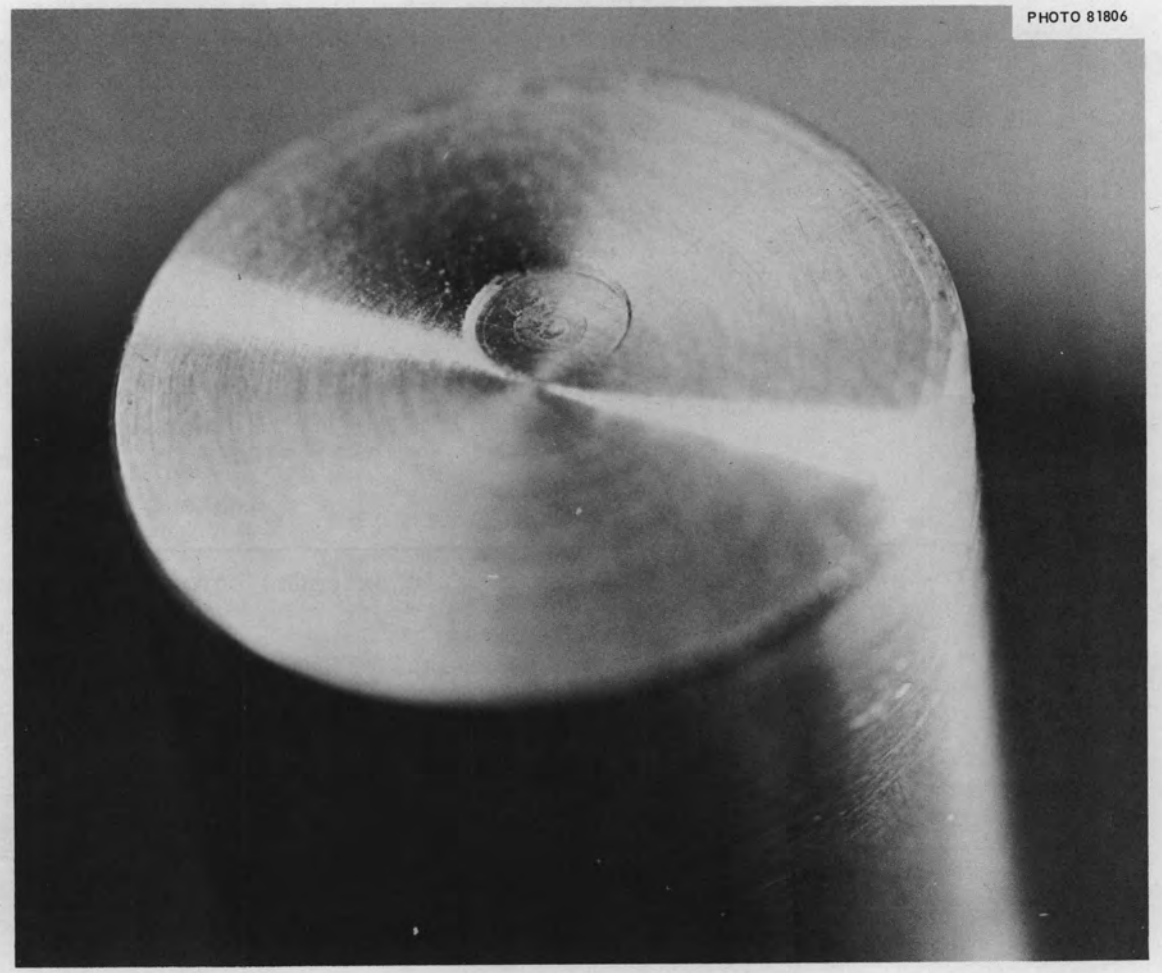

Fig. 4.34. R-Cs-157-1B After Class II Puncture Resistance Test.

4.2.3. Iridium

4.2.3.1. R-Ir-85. Six inactive sources of this type were acquired for the test program. The source material was crimp sealed in a 2S aluminum capsule (0.25-in. dia by 0.397-in. overall length before crimping). The capsule had a 0.125-in. nominal wall thickness. Table 4.22 gives the test results for this source type.

Table 4.22. Test Results on R-Ir-85 Sources

Source	Type of test	Conditions	Results
A	Leak	Initial vacuum	Leaked
B	Leak	Initial vacuum	No leaks
	Maximum temperature	1000°F for 24 hr	Leaked
C	Leak	Initial vacuum	Leaked
D	Leak	Initial vacuum	No leaks
E	Leak	Initial vacuum	No leaks
	External pressure	22,000 psig for 1 hr	No leaks
F	Leak	Initial vacuum	No leaks
	Crushing	200 lb	Flattened to 0.165 in.
	Crushing	500 lb	Flattened to 0.131 in.; leaked

4.2.3.2. R-Ir-111. Three 6-mm-dia by 6-mm-long sources encapsulated in aluminum were obtained for testing (Fig. 4.35). The tests performed on each source and the results are given in Table 4.23.

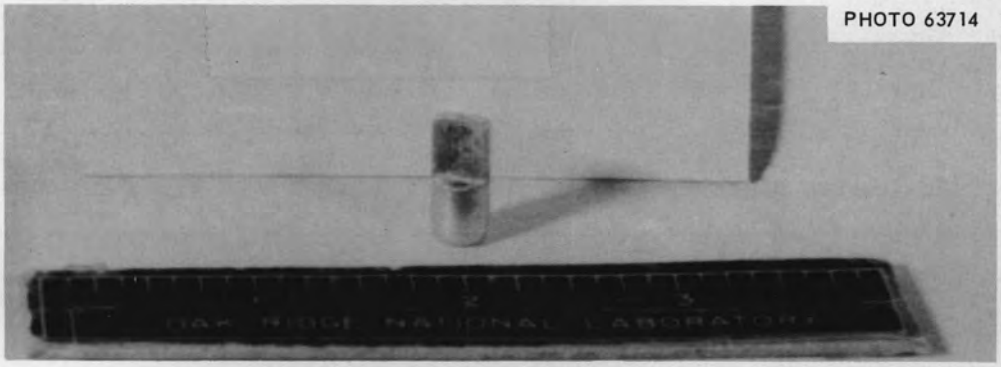

Fig. 4.35. R-Ir-111 as Received.

Table 4.23. Test Results of R-Ir-111 Sources

Source	Type of test	Conditions	Results
A	Temperature resistance	750°F for 1 hr in air, then to -40°F for 24 hr	No leaks
	Puncture resistance	8 ft onto 1/8-in.-dia pin	No leaks
B	Operating temperature	212°F for 24 hr	No leaks
	External pressure	22,000 psig for 1 hr	No leaks
C	Crushing	200 lb for 1 hr	No leaks

4.2.4. Thulium (R-Tm-8)

Seven 3.6-g sealed sources were obtained for testing. Each source was cylindrical in shape (0.285 in. in dia, 0.8 in. in length) and singly encapsulated in stainless steel. The tests performed on each source and the results are given in Table 4.24.

Table 4.24. Test Results of R-Tm-8 Sources

Source	Type of test	Conditions	Results
A	Smear	Filter paper	70 dis/min
	External pressure	300 psig for 1 hr	Leaked (wt gain)
	External pressure (hot-water leak)	90 psig for 1 hr, then ~200°F for 5 min	No leaks observed
1A	Crushing	1000 lb for ~1 min	Leaked
Sources 1B and 1C not tested			
2A	Maximum temperature	1700°F for 1 hr in air	Leaked
2B	Temperature resistance	750°F for 1 hr, then to -76°F for 24 hr	No leaks
	Operating temperature	212°F for 24 hr in air	No leaks
	Thermal shock	212 to 32°F	No leaks
	Impact	12 lb from 5 ft	No leaks
2C	Crushing	200 lb for 1 hr	No leaks
	Shear	100 lb for 1 hr	No leaks
	Puncture	35 g from 5 ft	No leaks
	External pressure	17,500 psig	Failed

4.3. Neutron Sources

Tests were made on three types of neutron sources which had a polonium-beryllium alloy as the source material. All three used stainless steel capsules and a weld seal closure. Model N-PoBe-57 was smaller (see Table 4.25) and the first four samples of this type were closed with a screw plug back-filled with soft solder.

Table 4.25. Dimensions of Polonium-Beryllium Neutron Sources

Source No.	Diameter, in.	Length, in.	Weight, g
N-PoBe-57	0.625	1	33
N-PoBe-62	1.0	4-1/4	580
N-PoBe-63	1.0	4-7/16	587.5

Subsequent samples of N-PoBe-57 were closed with a continuous weld seal, and this modification of the model was given a classification in the ORNL Source Capsule Classification System.

All tests were made using capsules containing nonradioactive material. (One sample of N-PoBe-57 did contain radioactive material, but this unit was not used in the testing program.)

4.3.1. N-PoBe-57

4.3.1.1. Screw Plug with Solder. Initial vacuum leak tests revealed no leaks in these samples; however, a dye penetrant check indicated some very tiny cracks in the solder. One sample was heated to 1700°F in air for 1 hr. Examination at the end of the test period showed that the solder had melted from the closure end. This unit was sectioned, but there was no indication that the source had leaked. In a second temperature test at 750°F, the solder melted from the sealed end after ~5 min exposure in the furnace.

4.3.1.2. Weld Seal. Test results on this type of source are summarized in Table 4.26.

Table 4.26. Test Results on Source Model N-PoBe-57 (Weld Seal)

Class	Type of test	Results
C	Maximum Temperature Resistance	No damage, no leaks
C	Operating Temperature Resistance	No damage, no leaks
C	Thermal Shock Resistance	No damage, no leaks
D	Thermal Shock Resistance	Microscopic examination showed no cracks in capsule or weld; no leaks
III	External Pressure Resistance	No damage, no leaks
V	Puncture Resistance	Scratched but no indentation; no leaks
III	Resistance to Shear	Small indentation, no cracks; no leaks
III	Impact Force Resistance	Flattened from 0.625 to 0.611 in., no breaks in weld; no leaks

Source N-PoBe-57 with the weld closure was given a C-III classification.

4.3.2. N-PoBe-62 and N-PoBe-63

The results of the test program on these two models are summarized in Table 4.27.

Table 4.27. Results of Testing on Neutron Source Models N-PoBe-62 and N-PoBe-63

Class	Type of test	Results	
		N-PoBe-62	N-PoBe-63
	Vacuum leak	No evidence of leaks	
C	Maximum Temperature Resistance	Slight oxidation, no leaks	
D	Operating Temperature Resistance	No damage, no leaks	
C	Thermal Shock Resistance	No damage, no leaks	
III	Puncture Resistance	No penetration, no leaks	
III	Resistance to Crushing	No damage, no leaks	
III	Impact Force Resistance	No damage, no leaks	
IV	Resistance to Shear	No visible damage, no leaks	
V	Resistance to Shear	Not applied to this model	Slight indentation, offset ~0.004 in., no rupture, no leaks

The neutron source models N-PoBe-62 and N-PoBe-63 were given a C-III classification. Figure 4.36 compares a new N-PoBe-62 source with a N-PoBe-62 source after it was subjected to the Class III Maximum Temperature Resistance test.

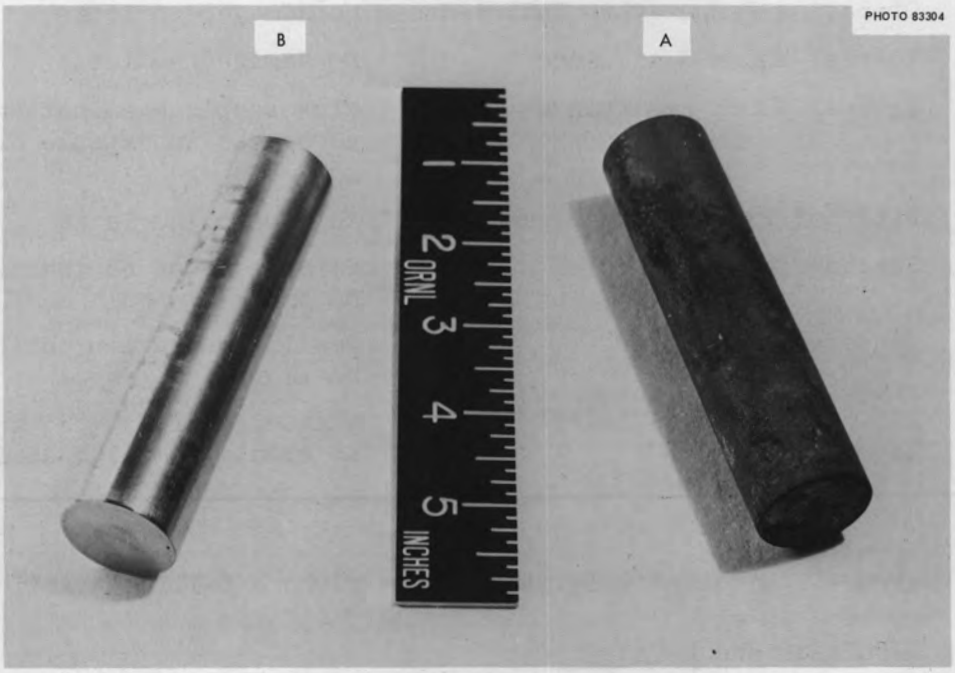

Fig. 4.36. N-PoBe-62 After Class III Maximum Temperature Resistance Test (A) Compared With an Untested Source (B).

4.4. Beta and Gamma Gages

4.4.1. Krypton

Six krypton gage sources of one type and eight of another type were obtained for testing. The dimensions of the cylindrical sources are given in Table 4.28.

Table 4.28. Dimensions of Krypton Gage Sources

Source	Material	Weight, g	Diameter, in.	Length, in.
G-Kr-52	Aluminum	18	~0.5	~0.625
G-Kr-53	Stainless steel	12	~0.75	1.50

The aluminum sources had a thin mica window and were mounted in an aluminum base (0.938-in. dia by 0.437-in. height); three were mounted with a resinous material, three with pins. When the first source was vacuum leak tested, air bubbles were observed around the base of the source but the krypton chamber did not leak. The source was immersed in a dye solution under 26 in. of Hg; and when the source was removed for inspection, no dye penetration was observed. One side of the base was sawed off to determine the source construction. During the sawing operation, enough heat was generated to loosen the krypton chamber adhesive and the chamber was removed from its base. The mica window of this source ruptured under 40-psig internal pressure (Fig. 4.37). The source capsule began collapsing at 2200 lb of force.

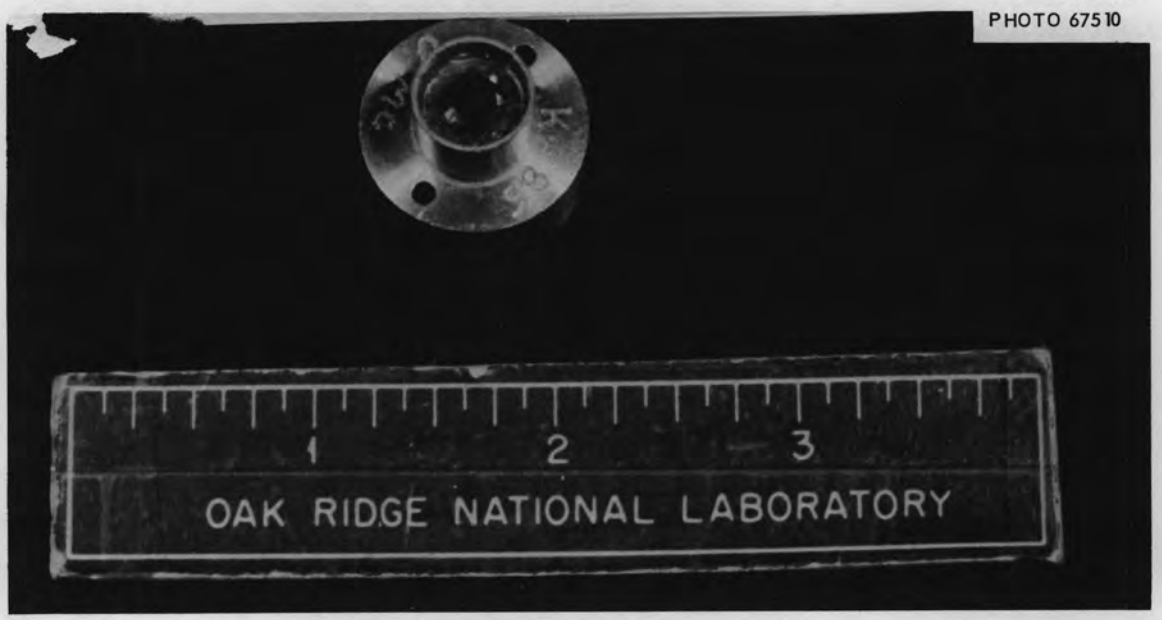

Fig. 4.37. G-Kr-52 Showing Ruptured Mica Window After Internal Pressure Test.

The second source was placed in an environmental chamber and the temperature was increased to 122°F and held for a 2-hr period. The adhesive material softened enough to allow the source to separate from its base. The mica window withstood 70-psig external pressure without rupturing or developing a leak. This same window ruptured at 15 psig during a subsequent internal pressure test.

The third source was dipped in water at 176°F for ~1 min. When removed, the krypton chamber and adhesive material were easily removed from the base. The source was then immersed in boiling water for 20 min. The source did not leak after this test, and there was no apparent damage to the mica window. Figure 4.38 shows these first three sources after testing.

1 2 3

Fig. 4.38. G-Kr-52 Sources After Testing.

The krypton chambers of the next three sources were fastened to the base with pins. The first source of this set leaked during the initial vacuum leak test at the point of bonding between the mica window and the aluminum capsule. The second source also leaked (the inner cavity of the source was filled with ethylene glycol when the vacuum was released at the end of the leak test). The third capsule did not leak initially. During the puncture test on this source the mica window ruptured. (Source was positioned with window resting on a 1/8-in.-dia pin, and a 20-g weight was dropped on the source from a height of 33 in.) The capsule withstood a shear test of 1000-lb force applied for 1 hr and was then sheared to failure at 4200 lb of force.

None of the eight stainless steel sources (G-Kr-53) leaked when subjected to the initial leak test. Results of the various tests performed on the first group of four sources are given in Table 4.29.

Table 4.29. Test Results of G-Kr-53 Sources (First Series)

Source	Type of test	Conditions	Results
A	Impact	60 g from 2 in. to 4 ft	No leaks
	Maximum temperature	750°F for 1 hr in air	No leaks
	Operating temperature	212°F for 24 hr in air	No leaks
	Operating temperature	-40°F for 24 hr in air	No leaks
	Thermal shock	212 to 0 to -76°F for 15 min	No leaks

Table 4.29 continued

Source	Type of test	Conditions	Results
2A	Maximum temperature	750°F for 1 hr in air	No leaks
	Operating temperature	212°F for 24 hr in air	No leaks
	Operating temperature	-40°F for 24 hr in air	No leaks
	Thermal shock	212 to 0 to -76°F for 15 min	No leaks
	Puncture	20 g from 5 ft	Punctured
	Puncture	20 g from 21 in.	Punctured
	Crushing	50-lb force from 1-in.-dia piston	Collapsed
2B	Puncture	75 g from 5 ft	Punctured
2C	Crushing	150 lb	Collapsed

Figure 4.39 shows G-Kr-53 sources: A — before testing, B — after external pressure test, C — after internal pressure test.

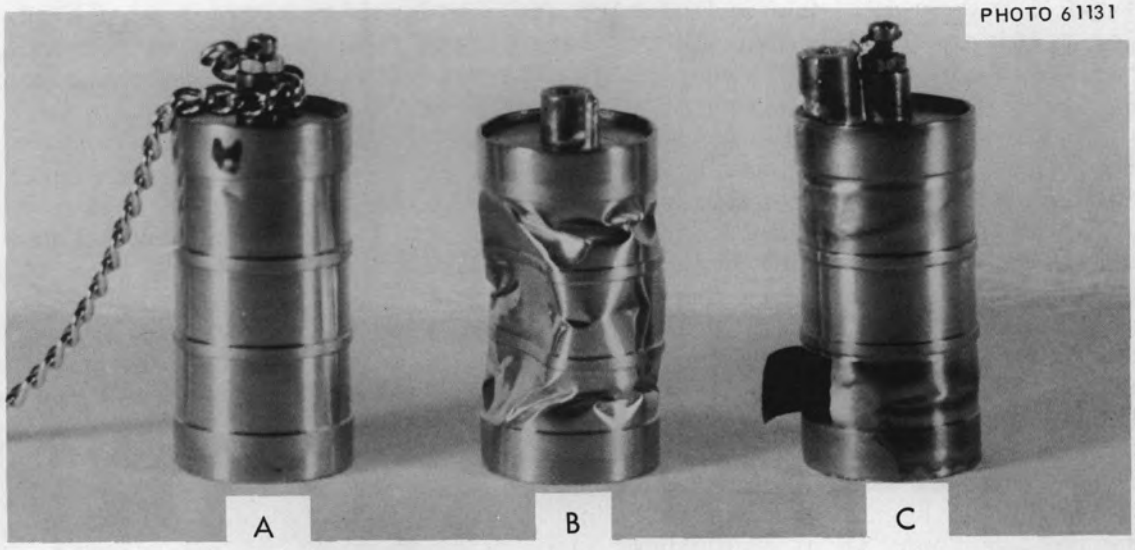

Fig. 4.39. G-Kr-53: A — Before Testing, B — After External Pressure Test, C — After Internal Pressure Test.

The last four sources were obtained for classification according to the ORNL classification system. G-Kr-53 was classified as B-I after undergoing the tests listed in Table 4.30.

Table 4.30. Test Results of G-Kr-53 Sources (Second Series)

Source	Type of test	Conditions	Results
3A	Puncture	23 g from 4 ft	Punctured
3B	External pressure	100 psig for 1 hr	No leaks but collapsed at 85 psig
3C	Crushing	200 lb for 15 min	No leaks
	External pressure	30 psig for 1 hr	No leaks
	Puncture	12.1 g from 3 ft	No leaks
	Shear	40 lb for 1 hr	No leaks
3D	Operating temperature	-76°F for 24 hr in air	No leaks
	Operating temperature	212°F for 24 hr in air	No leaks
	Maximum temperature	750°F for 1 hr in air	No leaks
	Thermal shock	212 to 0 to -76°F for 15 min	No leaks
	Impact	4 lb from 5 ft	Crushed

4.4.2. Strontium

4.4.2.1. G-Sr-12. One radioactive and six inactive sources were obtained for testing. The ~12.3-g sources were in the form of enameled steel disks, ~1-1/4 in. in dia by 1/8 in. thick. The activity was sealed in the center of the disks between layers of mica, ~5/16 in. in dia.

The radioactive source was boiled in water for 6 hr. A water sample showed ~0.012 μc of activity; a smear of the source for transferable activity showed 0.0079μc. A visual inspection of the source did not reveal any defects. A 1-in.-dia steel ball weighing 67 g was dropped from heights up to 3 ft onto the mica window; however, the recessed window prevented full impact by the ball. After each impact, the source was smeared with absorbant filter paper for transferable activity and inspected under magnification. No significant amount of activity or damage to the source was found. The source was positioned vertically and the 67-g steel ball was dropped from the same heights. The source was smeared after each impact, but no significant activity or damage was found (Fig. 4.40 shows the source after testing). A vacuum leak test conducted four months later indicated that the source had a leak.

Fig. 4.40. G-Sr-12 (Radioactive Source) After Testing.

The initial vacuum leak tests of the six inactive sources indicated leaks. The sources were placed in a dye penetrant solution under vacuum. Dye solution penetrated all of the sources, and microscopic examination showed small cracks in the mica windows of each source.

4.4.2.2. G-Sr-33. One radioactive and two inactive sources were obtained for testing. The sources were stainless steel rectangles (1-3/4 x 3/4 x 1/8 in.) with an oval machined depression to contain the welded stainless steel tube of radioactive material. The tube was overcoated with a ceramic material (Fig. 4.41.A).

Fig. 4.41. G-Sr-33 as Received (A) and After Immersion in Ultrasonic Cleaner for One Hour (B).

The initial smear of the 20-mc ^{90}Sr source was below the limit of detection. The source was placed in boiling water for 2 hr and smeared again; the transferable activity of the smear was below detection. No leaks were detected during the vacuum leak test.

The first of the inactive sources (1A) was immersed in an ultrasonic cleaner containing water. After 1 hr, some of the ceramic material had flaked off exposing the stainless steel tube which ordinarily contains the radioactive material (Fig. 4.41B). The second source (1B) was immersed in an ultrasonic flaw detector scanning tank and left overnight. When the source was removed, part of the ceramic material had flaked off. The source was then soaked in water for 48 hr; no further flaking of the ceramic material was noted.

4.4.2.3. G-Sr-102. One radioactive and two inactive sources were obtained for testing (Fig. 4.42 shows a source as received). The sources were stainless steel cylinders, 7/8 in. in dia by 7/16 in. high, with welded 0.015-in.-thick windows.

Fig. 4.42. G-Sr-102 as Received.

The initial vacuum leak tests did not show any leaks in either of the inactive sources. Source 1A was heated in a furnace at 1700°F for 30 min. Upon removal of the source, a crack extending three-fourths of the way across the window surface was seen (Fig. 4.43). The interior material had not melted or changed shape as a result of the test. When the second inactive source (1B) was dropped from 3 ft onto a 1/8-in.-dia pin, the thin window ruptured (Fig. 4.44). Due to the results of the tests on the inactive sources, the 5-mc ^{90}Sr source was not tested.

Fig. 4.43. G-Sr-102-1A After Being Subjected to 1700°F for 30 Min.

Fig. 4.44. G-Sr-102-1B After Puncture Resistance Test.

4.4.2.4. G-Sr-104. One radioactive and two inactive sources were obtained for testing. The sources were stainless steel cylinders (7/8 in. in dia by 7/16 in. high) with thin (0.005 in.) welded windows. Figure 4.45 shows a sectional view of this model.

Fig. 4.45. Sectional View of G-Sr-104.

When examined with a stereomicroscope, a very shallow crack was seen in the weld of one inactive source (1A), but the source did not leak when subjected to a vacuum leak test. The source was placed in an oven at 1700°F in air for 30 min. Upon removal from the oven, the source window which had oxidized severely crumbled and broke away exposing the inactive material. The second source (1B) withstood a crushing force test of 500 lb applied to the source placed in a vertical position and did not leak after this test. No further tests were conducted on the source since an identical source with a thicker (0.015 in.) window (G-Sr-102) had demonstrated insufficient puncture resistance to be classified according to the ORNL Source Capsule Classification System. Due to the results of the tests on the inactive sources, the 5-mc ^{90}Sr source was not tested.

4.4.2.5. Gages Recovered After Factory Fire (G-Sr-186A through E). Five beta gage sources which withstood a factory fire were examined. Each source capsule was a 1/2-in.-dia by 1/4-in.-high right circular cylinder with a 1.5-mil-thick window brazed to the body of the source. Each source had been prepared by depositing 10-12 mc of ^{90}Sr on a ceramic disk, covering the radioactivity with a silicate, and baking the unit. The ceramic disk was then placed in the capsule with the radioactive end adjacent to the thin window, and the capsule was closed with a threaded plug sealed in place with silver solder.

Two of the sources had been on the second floor of the building which burned and had fallen to the first floor during the fire. The maximum temperature reached during the fire is not known; however, the aluminum housings had melted. Copper wires attached to the device did not appear to have been affected by the heat.

When G-Sr-186A was cleaned with weak nitric acid and a soft wire brush, it regained most of its original luster (Figs. 4.46 through 4.49). The solder on the threaded plug closure had melted off in the fire, and a small leak was detected through the threads. The window was slightly corroded but did not leak. G-Sr-186B (Figs. 4.50 through 4.53) also regained its luster and very little of the solder had melted although the window which had buckled and cracked did leak. The window of G-Sr-186C (Figs. 4.54 through 4.57) was also buckled and appeared cracked, but the source did not leak in the vacuum leak test. About half of the solder had melted off the threaded plug, and the source appeared to leak momentarily when subjected to the leak test. It was concluded, however, that the apparent leak resulted from air trapped in the threads.

Fig. 4.46. G-Sr-186A,
Window Side Before Cleaning.

Fig. 4.47. G-Sr-186A,
Window Side After Cleaning.

Fig. 4.48. G-Sr-186A,
Screw Plug Side Before Cleaning.

Fig. 4.49. G-Sr-186A,
Screw Plug Side After Cleaning.

Fig. 4.50. G-Sr-186B,
Window Side Before Cleaning.

Fig. 4.51. G-Sr-186B,
Window Side After Cleaning.

Fig. 4.52. G-Sr-186B,
Screw Plug Side Before Cleaning.

Fig. 4.53. G-Sr-186B,
Screw Plug Side After Cleaning.

Fig. 4.54. G-Sr-186C,
Window Side Before Cleaning.

Fig. 4.55. G-Sr-186C,
Window Side After Cleaning.

Fig. 4.56. G-Sr-186C,
Screw Plug Side Before Cleaning.

Fig. 4.57. G-Sr-186C,
Screw Plug Side After Cleaning.

Source G-Sr-186D (Figs. 4.58 through 4.61) was embedded in a large piece of aluminum which had resolidified. The retainer plug from the device was fused to the threaded plug of the source. When cleaned, the source had a fine crack which extended around its circumference. The window was badly oxidized and parts of it were missing. Source G-Sr-186E, still in the shutter mechanism of the gaging device, was somewhat distorted from the fire. There was no evidence of leakage, and close visual examination did not reveal any damage.

Sources G-Sr-186A, C, and E were cleaned to levels which indicated that the sources did not leak an appreciable amount of radioactive material. Sources G-Sr-186B and D leaked considerably; however, most of the activity remained within the source. This was probably due to the form of the source material (silicate-coated ceramic) which tended to fix the activity in place even though the capsule had failed.

4.4.3. Cobalt

4.4.3.1. G-Co-11. A total of nine 3-g sources were obtained for testing. The sources (Fig. 4.62) were doubly encapsulated in stainless steel and were 0.25 in. in dia by 0.642 in. in length. The initial vacuum leak tests disclosed no leaks. The tests performed on the first group of six sources and the results are given in Table 4.31.

Table 4.31. Test Results on G-Co-11 Sources (First Series)

Source	Type of test	Conditions	Results
1A	Maximum temperature	1700°F for 1 hr in air	No damage
	Operating temperature	750°F for 24 hr	No damage
	Operating temperature	-320°F for 24 hr	No damage
	Thermal shock	500 to 32°F, then to -76°F for 15 min	No leaks
	Maximum temperature	2550°F for 1 hr in air	Source melted
1B	Impact	12 lb from 5 ft	Cracked
1C	Crushing	2000 lb for 1 hr	Cracked
1D	Impact	6 lb from 5 ft	Cracked
1E	Crushing	200 lb for 1 hr	No leaks
	Impact	5 lb from 4 ft	Cracked
1F	Shear	100 lb for 1 hr	No leaks
	Puncture	20 g from 30 in.	No leaks
	Puncture	40 g from 5 ft	No leaks
	Thermal shock	1700 to -76°F	No leaks

Fig. 4.58. G-Sr-186D,
Window Side Before Cleaning.

Fig. 4.59. G-Sr-186D,
Window Side After Cleaning.

Fig. 4.60. G-Sr-186D,
Screw Plug Side Before Cleaning.

Fig. 4.61. G-Sr-186D,
Screw Plug Side After Cleaning.

Fig. 4.62. G-Co-11 as Received.

Three additional sources were obtained for testing and the results are given in Table 4.32.

Table 4.32. Test Results of G-Co-11 Sources (Second Series)

Source	Type of test	Conditions	Results
2A	Puncture	7 g from 4 ft	No leaks
	External pressure	100 psig for 1 hr	No damage
	Crushing	200 lb for 1 hr	No leaks
	Shear	100 lb for 1 hr	No leaks
	Impact	6 lb from 5 ft	Appeared to leak
2B	Operating temperature	-320°F for 24 hr	No leaks
	Operating temperature	500°F for 24 hr in air	No damage
2C	Thermal shock	500 to 32°F, then to -76°F for 15 min	No leaks
	Maximum temperature	1700°F for 1 hr in air	No leaks

4.4.3.2. G-Co-34. A total of ten ~507-g sources were obtained for testing. The ~4-in.-long by 0.892-in.-dia sources were encapsulated in welded stainless steel with thin end windows (Fig. 4.63). The initial vacuum leak tests disclosed no leaks. The tests performed on the first group of six sources and the results are given in Table 4.33.

Fig. 4.63. G-Co-34 as Received.

Table 4.33. Test Results of G-Co-34 Sources (First Series)

Source	Type of test	Conditions	Results
1A	Maximum temperature	1700°F for 1 hr in air	No leaks
	Maximum temperature	2550°F	Capsule burst after ~10 min
1B	Impact	12 lb from 5 ft	No leaks
	Puncture	507 g from 15 ft	Leaked
	Crushing	20,000 lb	No additional damage
1C	Shear	40,000 lb for 1 hr	No leaks
2A	Operating temperature	500°F for 24 hr in air	No leaks
	Operating temperature	-320°F for 24 hr	No leaks
2B	Puncture	507 g from 8 ft	No leaks
	Thermal shock	1700°F in air to -76°F	No leaks
	Shear	24,000 lb for 1 hr	No damage
	Puncture	800 g from 5 ft	Punctured window
2C	Puncture	510 g from 3 ft	No leaks

Tests on the second group of four sources was for the purpose of classifying the source according to the ORNL Source Capsule Classification System. G-Co-34 was classified as C-II after undergoing the tests listed in Table 4.34. Figure 4.64 shows G-Co-34-3B after the puncture test.

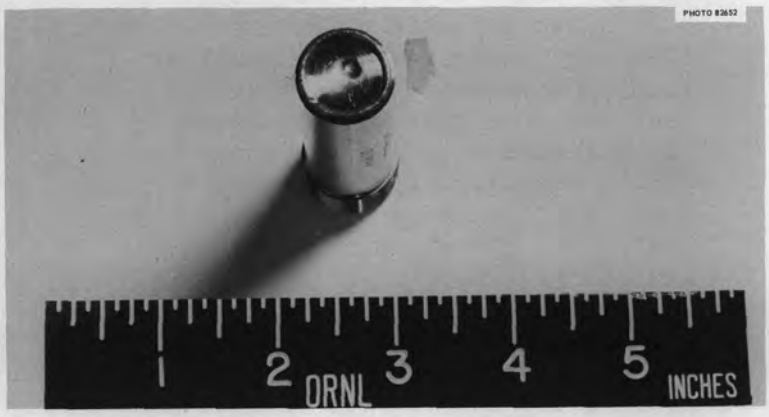

Fig. 4.64. G-Co-34-3B After Puncture Resistance Test.

Table 4.34. Test Results of G-Co-34 Sources (Second Series)

Source	Type of test	Conditions	Results
3A	Operating temperature	-320°F for 24 hr	No leaks
	Operating temperature	500°F for 24 hr in air	No leaks
	Impact	12 lb from 5 ft	No leaks
	Puncture	510 g from 3 ft	No leaks
3B	Shear	1000 lb for 1 hr	No leaks
	Crushing	2000 lb for 1 hr	No leaks
	Puncture	630 g from 5 ft	No leaks

Table 4.34. continued

Source	Type of test	Conditions	Results
3C	External pressure	1000 psig for 1 hr	No damage
	Thermal shock	500 to 0, then to -76°F for 15 min	No leaks
	Maximum temperature	1700°F for 1 hr	No leaks
Source 3D was not tested			

4.4.3.3. G-Co-183, G-Co-184, and G-Co-185. Three old ^{60}Co sources were obtained for testing. One of the sources (G-Co-184) appeared to leak in the vacuum leak test, but no significant transferable activity was detected by smear tests. No deterioration of the welded joints on the other two sources (G-Co-183 and G-Co-185) could be detected under 80X magnification. The solder joint on the leaking source (G-Co-184) appeared slightly corroded under 80X magnification, and the seal was easily broken when the screw cap was removed.

4.4.3.4. G-Co-187. This was an ~6-year-old ^{60}Co source and Fig. 4.65 shows the unit as received. After examination under magnification and dye penetrant and vacuum leak tests, a leak was located on the threaded plug closure where the solder was missing. The initial smear for transferable activity read 2.5×10^5 dis/min. The leak was attributed to wear and old age.

Fig. 4.65. G-Co-187 as Received.

4.4.4. Cesium

4.4.4.1. G-Cs-54. Six 10-g sources singly encapsulated in stainless steel cylinders (0.495 in. in dia by 0.705 in. long) sealed with silver solder were obtained for testing. The initial leak tests disclosed no leaks. The tests performed and the results are given in Table 4.35.

Table 4.35. Test Results of G-Cs-54 Sources

Source	Type of test	Conditions	Results
1A	Shear	6240 lb	Sheared
1B	Maximum temperature	1700°F for 1 hr in air	Solder melted
1C	Maximum temperature	750°F for 1 hr in air	No leaks
	Operating temperature	-76°F for 24 hr in air	No leaks

Table 4.35. continued

Source	Type of test	Conditions	Results
1C	Operating temperature	212°F for 24 hr in air	No leaks
	Thermal shock	212 to 32°F	No leaks
	Impact (horizontal)	12 lb from 5 ft	No leaks
	Impact (vertical)	12 lb from 5 ft	No leaks
	Dye penetrant	Immersed for 10 min at pressure of -26 in. Hg	No leaks
1D	Impact	6 lb from 5 ft	No leaks
	Puncture	120 g from 5 ft	No leaks
	Impact	15 lb from 8 ft	No leaks
1E	Crushing	2000 lb for 1 hr	No leaks
	Puncture	30 g from 5 ft	No leaks
	External pressure	22,000 psig for 1 hr	No leaks
1F	Shear	1000 lb for 1 hr	No leaks
	Crushing	20,000 lb	Collapsed

G-Cs-54 was not classified according to the ORNL classification system since this model is no longer in production.

4.4.4.2. G-Cs-64. Six inactive sources and one radioactive source containing 0.1 mc of ^{137}Cs were obtained. The sources were aluminum disks, ~1.5 in. in dia by 3/16 in. thick. The source material was contained in a welded stainless steel tube (0.040 in. in dia by 1.0 in. long) which was installed in a 1.25-in.-long by 0.25-in.-wide oval slot and overcoated with a ceramic material. Figure 4.66.A shows the source as received. (The construction is similar to G-Sr-33, Fig. 4.41.A.) The ceramic material was coated with an enamel in order to obtain a smooth surface. The tests performed and the results are shown in Table 4.36.

Table 4.36. Test Results of G-Cs-64 Sources

Source	Type of test	Conditions	Results
1A	Thermal shock	212 to -320°F	No damage
	Bend	500 lb	Source bent
1B	Immersion	H_2O for 24 hr	No damage
1C	Immersion	1.0 N HNO_3 for 1 hr	Enamel dulled
	Immersion	1.0 N NaOH for 1 hr	Aluminum slightly attacked

Table 4.36. continued

Source	Type of test	Conditions	Results
1C	Immersion	1.0 N H_2SO_4 for 1 hr	Enamel soft and powdery
1D	Maximum temperature	1470°F for 30 min in air	Enamel blistered
1E	Vibration	Vibrated for 1 hr	No damage
	Temperature-humidity	32°F–0% RH to 212°F–100% RH over 24 hr	No damage
1F	Immersion	Alcohol for 1 hr	No damage
	Impact	60-g ball (1 in. dia) from 2-36 in.	Removal of enamel and ceramic material[a]
A[b]	Maximum temperature	750°F for 1 hr	No transferable activity
	Operating temperature	212°F for 24 hr in air	No damage
	Operating temperature	-40°F for 24 hr in air	No damage
	Thermal shock	212 to 0°F	0.0014 μc on surface
	Immersion	15 ml H_2O for 96 hr	0.0055 μc

[a]After the 24-in. drop, the stainless steel tube was exposed.

[b]Radioactive source.

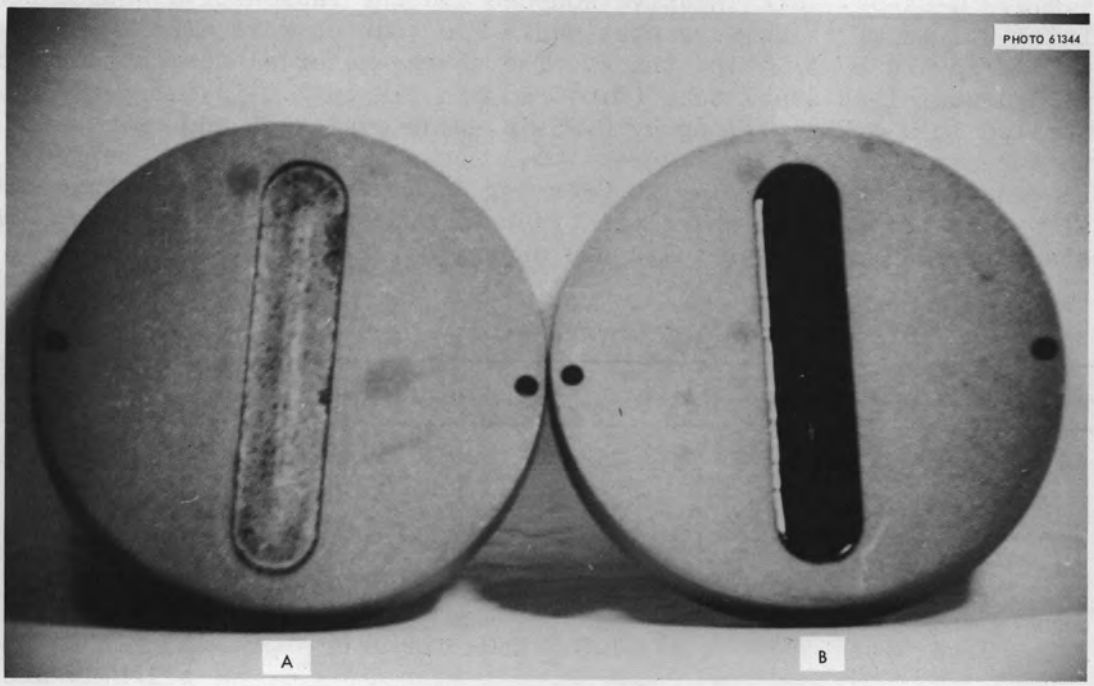

Fig. 4.66. G-Cs-64 as Received (A) and G-Cs-66 as Received (B).

Source G-Cs-64 was not classified according to the ORNL classification system because it is no longer in production.

4.4.4.3. G-Cs-66. Six inactive sources and one radioactive source containing 0.1 mc of ^{137}Cs were obtained for testing. These sources were similar to the G-Cs-64 sources except that the disks were composed of stainless steel instead of aluminum. Figure 4.66.B shows G-Cs-66 as received. The tests performed and the results are given in Table 4.37.

Table 4.37. Test Results of G-Cs-66 Sources

Source	Type of test	Conditions	Results
1A	Immersion	H_2O for 24 hr	Damaged
	Bend	880 lb	Source bent
1B	Immersion	1.0 N HNO_3 for 1 hr	Slight etching
	Immersion	1.0 N NaOH for 1 hr	No damage
	Immersion	1.0 N H_2SO_4 for 1 hr	More etching
1C	Thermal shock	212°F for 1 min to -320°F	Enamel and ceramic material flaked
	Ultrasonic	Cleaned for 1 hr	No damage
1D	Maximum temperature	1470°F for 30 min in air	No damage
1E	Immersion	Alcohol for 1 hr	No damage
	Impact	60-g ball (1-in. dia) from 2 to 36 in.	Ceramic material shattered[a]
1F	Vibration	Vibrated for 1 hr	No damage
	Temperature-humidity	32°F—0% RH to 212°F—100% RH over 24 hr	No damage
A[b]	Maximum temperature	750°F for 1 hr in air	No transferable activity
	Operating temperature	212°F for 24 hr in air	Same
	Operating temperature	-40°F for 24 hr in air	Same
	Thermal shock	212 to 0°F	Same
	Puncture	70 g from 4 ft	Same
	Impact	6 lb from 5 ft	Same

[a]Stainless steel tube still not exposed.

[b]Radioactive source.

4.4.4.4. G-Cs-199. Four inactive sources of this type were obtained for the testing program. This source was a right circular cylinder (0.5 in. long by 0.25 in. in dia) constructed of welded stainless steel (Fig. 4.67). Based on the test results (Table 4.38), G-Cs-199 was classified as B-III. Figure 4.68 shows G-Cs-199B after the Class III Impact Force Resistance test.

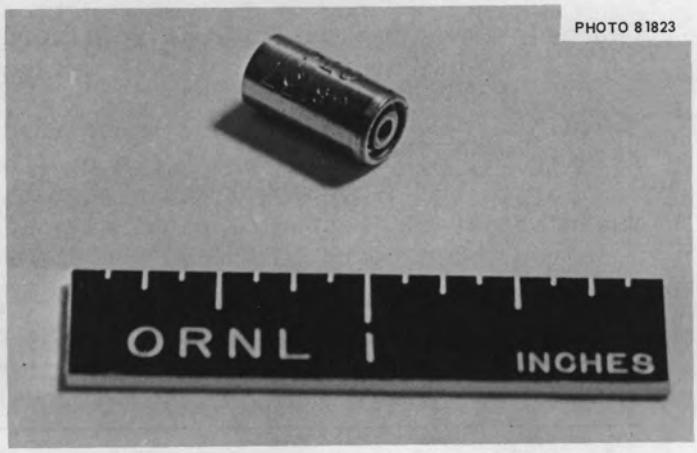

Fig. 4.67. G-Cs-199 as Received.

Table 4.38. Test Results on G-Cs-199

Source	Class	Type of test	Results
A	III	External Pressure Resistance	No leaks
	III	Puncture Resistance	No leaks
	III	Resistance to Crushing	No leaks
	III	Resistance to Shear	No leaks
B	B	Operating Temperature Resistance	
		Low	No leaks
		High	No leaks
	III	Impact Force Resistance	Flattened to 0.225 in., no leaks
C	B	Maximum Temperature Resistance	No leaks
	B	Thermal Shock Resistance	No leaks

Fig. 4.68. G-Cs-199B After the Class III Impact Force Resistance Test.

4.5. Calibration Sources

4.5.1. Sources Previously in Use

4.5.1.1. Old Sources. Four old calibration sources were sent to ORNL for examination in the source testing program. The dates of manufacture were not known, but three units (C-Sr-75, C-Sr-76, C-Sr-77) had originally contained 100 μc of ^{90}Sr, the fourth (C-Cs-78) initially held 0.7 mc of ^{137}Cs.

When C-Sr-75 was removed from its shipping container, it was so badly damaged there appeared to be no point in performing a leak test (Fig. 4.69). The source had apparently been opened by using a sharp object to pry the window, which was soldered to the source body. Examination under a stereomicroscope showed that the soldered joint had never been bonded. No tests were made on this unit.

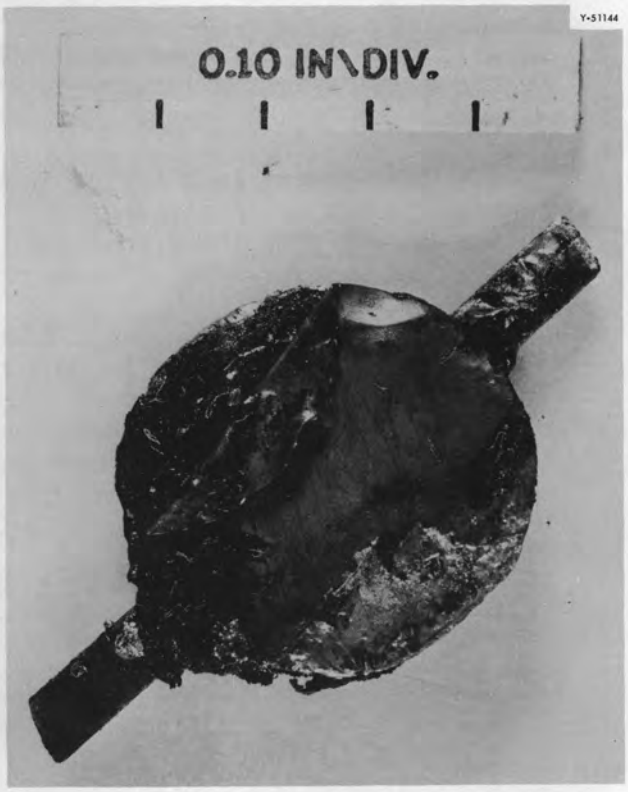

Fig. 4.69. C-Sr-75 as Received.

Source C-Sr-76 appeared to be leaking when received (Fig. 4.70) since an initial smear showed 4800 dis/min. Microscopic examination indicated that the source had been coated with a plastic-like material and that the plastic had broken down (it was cracked and blistered and in some places had peeled). The

Fig. 4.70. C-Sr-76 as Received.

coating material was dissolved from the source with acetone, and the source was again examined under the microscope. The solder joint appeared to be rough and bonded on only 50% of the area; however, a vacuum leak test did not disclose any leaks. The source was then placed in a container and 20 lb of helium pressure was applied for 1 hr. The source was also immersed in ethylene glycol and a vacuum applied. The source did not show evidence of a leak following these tests.

In a vacuum leak test on C-Sr-77, the source leaked readily from a point on the solder seal. Microscopic examination pinpointed the leak (Fig. 4.71) and no further tests were conducted on this unit.

Source C-Cs-78 was leak tested in ethylene glycol. The unit leaked badly from both ends which appeared to be soldered. Examination under magnification showed that the solder seals were not complete, and they could have caused the leakage. No other tests were performed on this source.

4.5.1.2. U. S. Navy Sources. A number of small U. S. Navy calibration sources were examined and found to leak. In most cases, these leaks appeared to have resulted from poor soldering during manufacture. These sources had been removed from usage because excessive transferable activity was found during periodic smear tests. The smear counts obtained from wipe tests of the sources are given in Table 4.39. Figure 4.72 shows C-Sr-24 as received; Fig. 4.73 is C-Sr-122.

Table 4.39. U. S. Navy Calibration Sources

Source	Source material	Source activity, μc	Navy smear results, μc	Source use
C-Sr-24	^{90}Sr	100	0.0026	Radiac set calibration
C-Sr-59	^{90}Sr	100	0.0051	Radiac set calibration
C-Sr-75	^{90}Sr	100	0.0065	Radiac set calibration
C-Sr-76	^{90}Sr	100	0.011	Radiac set calibration
C-Sr-77	^{90}Sr	1000	0.004	Radiac set calibration
C-Cs-78	^{137}Cs	700	0.011	D-8 } Pocket dosimeter calibration set
C-Cs-92	^{137}Cs	700	0.035	B-10 } Pocket dosimeter calibration set
S-Sr-97A,B	Exempt quantity of ^{90}Sr		a	Radiac set calibration
C-Sr-98	^{90}Sr	30	0.0055	Radiac set calibration
C-Cs-117	^{137}Cs	700	0.0063	B-11 } Pocket dosimeter calibration set
C-Cs-118	^{137}Cs	700	0.0067	B-15 } Pocket dosimeter calibration set
C-Sr-121	^{90}Sr	300	0.0068	Radiac set calibration
C-Sr-122	^{90}Sr	100	0.018	Radiac set calibration
C-Sr-123A,B	^{90}Sr	120	Unknown	Unknown
C-Sr-124	^{90}Sr	340	0.05	Radiac set calibration

[a]Surface contamination detectable.

Fig. 4.71. C-Sr-77 as Received (40X).

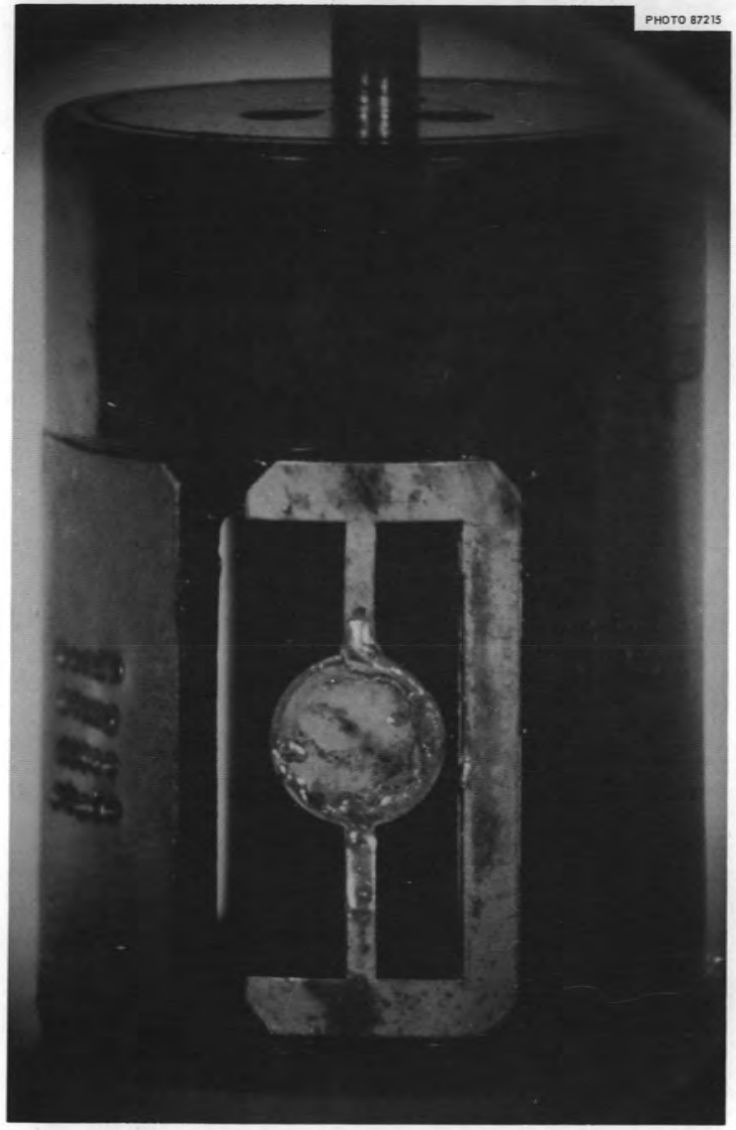

Fig. 4.72. C-Sr-24 as Received.

Fig. 4.73. C-Sr-122 as Received.

4.5.2. New Calibration Sources

Several different types of alpha calibration sources were tested: ^{241}Am count rate (C-Am-23A through C-Am-23F), ^{241}Am energy spectrum standard (C-Am-25A through C-Am-25D), ^{239}Pu count rate (C-Pu-22A through C-Pu-22D), and ^{239}U (C-U-44A through C-U-44C). Figure 4.74 is a magnified view of C-Am-23 as received. Although all of these sources are not considered to be sealed sources within the definition used for the ORNL Source Capsule Classification System (because the radioactive material is deposited on the outside surfaces of the holder), these units were tested to obtain an indication of how tightly the activity was held in place.

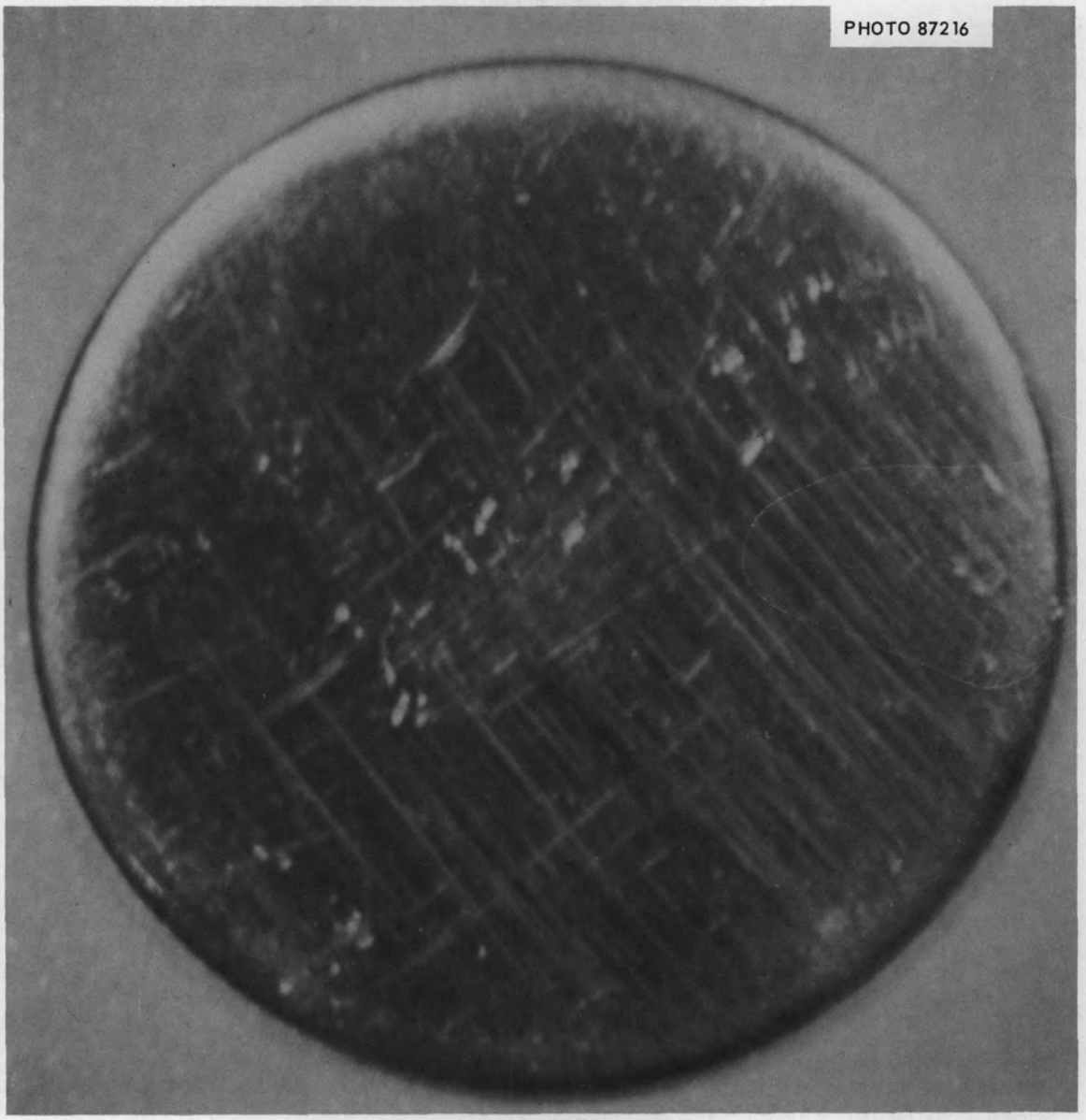

Fig. 4.74. C-Am-23 as Received (40X).

The tests included the following: (a) dry-wipe smear over the entire surface, (b) wet-wipe smear over the entire surface, (c) water-soak test in which the source was soaked in a minimum quantity of water (5-10 ml) for a period of 24 or 72 hr (in some instances this test was repeated after 30 and 90 days), (d) smear after the water-soak test to determine if soaking had loosened the material, and (e) smear using dry filter paper at different pressures to determine amount of pressure required to remove the greatest portion of transferable activity. Data from this testing program are tabulated in Tables 4.40 and 4.41.

Table 4.40. Test Results of Alpha Calibration Sources

	Activity detected, % of total activity[a]			
			After soak test	
Source	Dry smear	Wet smear	Water	Smear
Americium				
C-Am-23A	1.86	2.3	2.7	6.7
C-Am-23B	1.4	2.9	7.8	3.7
C-Am-23C			2.5	13.6
C-Am-23D			0.0[b]	2.3[b]
	1.1[c]		1[d]	2[d]
C-Am-25B			2.3	1.3
C-Am-25C			1.3	4.8
C-Am-25D			3.5[b]	0.63[b]
C-Am-71A	0.024		0.0	0.008
C-Am-71B	0.02			
C-Am-71C	0.001		0.0	0.025
C-Am-71D	0.04			
C-Am-71E	0.03		0.0	0.005
C-Am-71F	0.008			
Plutonium				
C-Pu-22A	0.0	0.0	0.021	0.0
C-Pu-22B	0.00036	0.00036	0.0	0.0011
C-Pu-22C			0.028[b]	0.0019[b]
	0.007[c]		0.0[d]	0.008[d]
Uranium				
C-U-44A			0.0	0.24
	0.7[c]		0.0[d]	0.2[d]
C-U-44B			2.7	1.7
	0.54[c]		2.5[d]	0.4[d]
C-U-72A			1.3	0.0
C-U-72B			2.4	0.15
C-U-72C			6.6	0.15
C-U-72D	0.06			

[a]According to manufacturer's specifications.
[b]Test made after 30 days.
[c]Smear taken before 90-day test.
[d]Test made after 90 days.

Table 4.41. Activity Removed From Calibration Sources as a Function of Pressure Applied to Smear Paper

Source	Activity removed, % of specified total activity[a]											
	0.5 psi	1 psi	2 psi	3 psi	5 psi	10 psi	12 psi	15 psi	20 psi	25 psi	30 psi	35 psi
Americium												
C-Am-23C							0.7	0.7	0.5	0.7	0.4	0.3
C-Am-23E						3.0		1.4	1.4			
C-Am-23F					1.3	0.8		0.4	0.3			
C-Am-25A	0.03	0.02		0.018	0.028	0.037		0.04	0.03	0.04	0.06	0.055
Plutonium												
C-Pu-22A	0.0009	0.0	0.0002	0.0								0.0
C-Pu-22B												0.0011
C-Pu-22C												0.002[b]
Uranium												
C-U-44A					0.5	0.7		0.5	0.9	1.0	0.9	
C-U-72D					0.06	0.0			0.0		0.0	
C-U-72F					0.0	0.06			0.0		0.06	

[a]According to manufacturer's specifications.

[b]Test made after 30 days.

The water-soak test was repeated on source C-U-44B over an extended period of time, and the results are given in Table 4.42. (Data on the test made after 90 days for this source from Table 4.40 are repeated for comparison purposes.)

Five sources in this group were subjected to temperature tests (see Table 4.43). Figure 4.75 shows C-U-44C after the temperature test.

Fig. 4.75. C-U-44C After Temperature Test.

Table 4.42. Activity Removed in Water-Soak Tests on Aged Calibration Source (C-U-44B)

	Activity detected, % of total activity[a]		
Days	Smear before soak test	Water after soak test	Smear after soak test
90	0.54	2.5	0.4
150	0.91	9.3	5.5
240	1.5	3.4	8.3
605	3.7	0.9	1.3
635	3.7	1.2	–

[a]According to manufacturer's specifications.

Table 4.43. Results of Temperature Test on Calibration Source

		Activity detected, % of total activity[a]			
Source	Test conditions	Smear	Filter	Cold trap	Scrubber
C-Am-23E	b	8.8	–	–	–
C-Am-25A	b	0.43	–	–	–
C-Pu-22D	b	0.027	–	–	–
C-U-44C	b	7.6	0.06	0.01	0.0
C-U-72B	c	–	7.8	0.0	0.0

[a]According to manufacturer's specification.
[b]Held in Bunsen burner flame for 5 min; vapors and combustion products pulled through cold trap and HCl scrub solution.
[c]Placed in quartz tube and heated to ~800°C; test terminated after 1 min because source material started to burn (cold trap – 3 N HNO_3).

4.6. Radiation-Activated Phosphors

4.6.1. Tritium- and Radium-Activated Phosphors

A study has been made to determine the amount and chemical form of tritium released from commercial tritium-activated phosphors. A single series of tests was also performed on one type of radium-activated phosphor. (The test materials were obtained from both foreign and domestic suppliers.) Samples of tritium-activated phosphors for the first series of tests were prepared by applying 0.1 g of the material to a 5-mil aluminum foil using binders furnished by the manufacturer and following the manufacturer's instructions. Samples of the radium-activated phosphor were prepared by the same method using 0.01 g of the material on each sample.

In the test procedure followed (a) samples were counted, (b) samples were vibrated for 1 hr at 60 cycles/sec and recounted, (c) samples were bent around a 1-in.-dia bar and visually inspected for damage, (d) samples were recounted, and (e) samples were placed in 100 ml of distilled water for 24 hr; water was then counted to determine activity lost from the sample.

The percentage of material lost to the distilled water was calculated from the water counts and the specific activity of the original phosphor.

Results of the investigation are given in Table 4.44. Samples W-H-27 through W-H-31 are tritium activated; W-Ra-26 is radium activated. There was no damage observed in any sample after the flection test.

Table 4.44. Results of Tests on Radiation-Activated Phosphors (Initial Series)

Sample number	Phosphor, mc/g	Activity: Counts/min[a] Beginning sample	After vibration	After flection	Leach water, dis/min.ml	Leaching loss, %
W-H-27-1	540	3068	3157	3093	5.42×10^5	0.045
-2		2954	3003	2770	6.19×10^5	0.052
-3		3067	3833	3322	5.73×10^5	0.048
W-H-28-2	335	2924	2835	2936	9.14×10^6	1.16
-3		2764	2637	2891	8.07×10^6	1.0
-4		2726	2628	2696	9.08×10^6	1.15
W-H-29-2	655	4655	4312	4376	1.67×10^7	1.15
-3		5298	4742	4744	1.55×10^7	1.07
-4		6100	5592	4764	1.52×10^7	1.05
W-H-30-2	1080	7598	7534	6753	2.59×10^7	1.08
-3		7606	7420	6144	3.29×10^7	1.37
W-H-31-1	Unknown	176	198	171	3.0×10^6	—
-2		150	191	149	2.4×10^6	—
-3		143	166	123	1.56×10^6	—

Table 4.44. continued

Sample number	Phosphor mc/g	Activity Counts/min[a] Beginning sample	After vibration	After flection	Leach water, dis/min.ml	Leaching loss, %
W-Ra-26-1	0.1	51,315	49,462	53,613	0.53	–
-2		48,074	46,658	46,381	6.81	–
-3		62,945	58,467	62,174	3.7	–

[a]Values are the average of three 5-min counts reduced to counts/min. A 5-min background count made before each set of determinations was subtracted from the values shown.

The degree of accuracy in the counting technique used was determined by weighing and counting prepared samples, removing a known quantity of material, and recounting the remaining sample (see Table 4.45).

Table 4.45. Data on Tests to Evaluate Counting Technique

Weight, g			Activity, counts/min			Reduction, %	
Before removal	After removal	Difference	Before removal	After removal	Difference	By weight	By count
0.1	0.075	0.025	3107	2129	978	25	31.5
0.1	0.048	0.052	3107	1592	1515	52	48.5
0.1	0.785	0.0215	3107	814	2293	78.5	73.5

4.6.1.1. Leach Testing of Aged Tritium Phosphors. The tritium-activated samples used in the first test series were resubjected to the water leach test after 90 days, 1 yr, and 2 yr to determine whether aging had any effect on the binders used in the paints (see Table 4.46).

Table 4.46. Tritium Lost from Phosphors During Leaching (Aged Samples)

Sample	Phosphor activity, mc/g	Leaching loss, % of sample activity: Initial	90-day	1-year	2-year
W-H-27-1	540	0.045	–	–	–
-2	540	0.052	0.054	0.047	0.51[a]
-3	540	0.048	0.054	0.053	2.02
W-H-28-2	335	1.16	0.68	0.64	4.08[a]
-3	335	1.0	0.68	0.57	3.22
-4	335	1.15	0.82	0.63	3.79

Table 4.46. continued

Sample	Phosphor activity, mc/g	Leaching loss, % of sample activity			
		Initial	90-day	1-year	2-year
W-H-29-2	655	1.15	1.03	1.26	6.59[a]
-3	655	1.07	0.59	0.79	4.86[a]
-4	655	1.05	0.52	0.69	4.24[a]
W-H-30-2	1080	1.08	1.14	1.8	6.0[a]
-3	1080	1.37	0.83	2.35	6.42
-4	1080	—	0.38	0.51	3.08
W-H-41-1	200	1.13	—	7.19	—
-2	200	0.11	—	1.84	—
-3	200	1.44	—	5.2	—
		Leaching loss, dis/min.ml			
		x 10^6	x 10^6	x 10^6	x 10^6
W-H-31-1	Unknown	3.0	3.71	5.15	7.52
-2	Unknown	2.4	2.62	4.29	7.32
-3	Unknown	1.56	1.71	3.60	7.42

[a]Large flecks of paint came off during soak period but figure reflects only the material which was dissolved in the water.

For a second series of tests on tritium-activated paint, new samples of the same five phosphors were obtained. Specimens were prepared by applying 50 mg of the phosphor to a 0.5-in.-dia countersunk surface on aluminum strips (1 x 3 x 0.05 in.). After curing, the entire specimen was washed with water to remove any loose activity. (Smears taken later indicated that the specimens were essentially free of transferable activity.)

Seven, 24-hr distilled-water leach tests were performed over a period of 11 months, and the results are tabulated in Table 4.47. The "B" and "C" samples were used as controls to determine whether repeated leaching affected the tritium loss; "B" was first tested 6 months after "A", "C" at 11 months after "A." Test results indicate that neither repeated leach testing nor aging had a major effect on tritium losses for paints WH-191 and WH-192. These two paints continued to show a considerably lower tritium loss than the other three paints.

Table 4.47. Tritium Loss with Sample Weight and Exposed Area Held Constant and Total Activity Varied

Sample	Total activity, mc	Tritium loss, % of activity						
		Initial	6 mo	7 mo	8 mo	9 mo	10 mo	11 mo
WH-192A	10.8	0.096	0.118	0.113	0.052	0.078	0.145	0.113
WH-192B	10.5	—	0.094	0.096	0.047	0.074	0.115	0.099
WH-192C	10.6	—	—	—	—	—	—	0.115
WH-193A	18.2	0.167	0.414	0.267	0.424	0.308	0.474	0.387
WH-193B	18.2	—	0.336	0.235	0.437	0.283	0.382	0.328
WH-193C	18.4	—	—	—	—	—	—	0.702
WH-191A2	27.1	0.062	0.022	0.024	0.025	0.018	0.026	0.023
WH-191B2	27.2	—	0.021	0.026	0.020	0.021	0.030	0.028
WH-191C2	27.1	—	—	—	—	—	—	0.027
WH-194A	31.9	0.231	0.595	0.382	0.612	0.434	0.731	0.668
WH-194B	32.7	—	0.678	0.379	0.628	0.438	0.670	0.581
WH-194C	32.9	—	—	—	—	—	—	1.296
WH-195A	52.6	0.169	0.457	0.297	0.327	0.329	0.534	0.430
WH-195B	52.5	—	0.535	0.320	0.389	0.362	0.592	0.501
WH-195C	52.8	—	—	—	—	—	—	0.873

4.6.1.2. Tritium Loss, Variable Conditions. Table 4.48 shows tritium losses as a function of exposed surface area. Each sample contained 27 mc of activity (50 mg of tritium-activated phosphor). As expected in a leaching process, the area of exposed surface appears to be an important variable.

Table 4.48. Tritium Loss with Variable Exposed Area

Sample	Tritium loss, % of activity						
	Initial	6 mo	7 mo	8 mo	9 mo	10 mo	11 mo
0.196 in.^{2} surface area							
WH-191A2	0.062	0.022	0.024	0.025	0.018	0.026	0.023
WH-191B2	—	0.021	0.026	0.020	0.021	0.030	0.028
WH-191C2	—	—	—	—	—	—	0.027
0.392 in.^{2} surface area							
WH-191A3	0.113	0.048	0.036	0.040	0.033	0.044	0.038
WH-191B3	—	0.052	0.036	0.081	0.030	0.037	0.037
WH-191C3	—	—	—	—	—	—	0.065

Table 4.49 shows the effect of paint thickness on tritium losses. The samples all had the same surface area and were prepared from the same paint used for the specimens in Table 4.48. The samples having a normal paint thickness contained 50 mg of tritiated phosphor; those with one-half normal paint thickness contained 27 mg of tritiated phosphor. The

lower losses for the thicker paint seem to indicate that the amount of tritium obtained in water leach tests depends more on the exposed surface area than on the total activity of the sample.

Table 4.49. Tritium Loss with Variable Paint Thickness Based on Initial Activity

Sample	Tritium loss, % of activity						
	Initial	6 mo	7 mo	8 mo	9 mo	10 mo	11 mo
Normal paint thickness							
WH-191A2	0.062	0.022	0.024	0.025	0.018	0.026	0.023
WH-191B2	–	0.021	0.026	0.020	0.021	0.030	0.028
WH-191C2	–	–	–	–	–	–	0.027
One-half normal paint thickness							
WH-191A1	0.083	0.039	0.043	0.040	0.032	0.052	0.048
WH-191B1	–	0.075	0.051	0.053	0.052	0.059	0.062
WH-191C1	–	–	–	–	–	–	0.007

In Table 4.50 the tritium losses are calculated on the basis of exposed surface area instead of the initial activity.

Table 4.50. Tritium Loss with Variable Paint Thickness Based on Exposed Surface Area

Sample	Tritium loss, mc/in.^{2}						
	Initial	6 mo	7 mo	8 mo	9 mo	10 mo	11 mo
Normal paint thickness							
WH-191A2	0.612	0.302	0.333	0.349	0.250	0.361	0.320
WH-191B2	–	0.290	0.358	0.274	0.284	0.409	0.388
WH-191C2	–	–	–	–	–	–	0.380
One-half normal paint thickness							
WH-191A1	0.856	0.286	0.319	0.282	0.234	0.381	0.351
WH-191B1	–	0.550	0.370	0.386	0.386	0.435	0.459
WH-191C1	–	–	–	–	–	–	0.485

4.6.1.3. Tritium Loss During Drying. In other tests,[8] aliquots of the tritium-activated organic polymer were mixed with binder and thinner in ceramic boats and then immediately introduced into the test apparatus. Air was pulled through the system at the rate of one bubble per second over a 4.5-hr period. The tritium loss was determined every 30 min for the first 1.5 hr and then every hour. The temperature of the paint was held at 28°C during the test to simulate conditions that occur in normal usage. Temperatures throughout the equipment were maintained at levels which would prevent tritium condensation. Tritium was removed from the

air stream by condensation in a trap held in a Dry Ice-acetone bath, and the air stream was further monitored for tritium by passing it through a water scrubber at room temperature.

In the second series of tests, the released gases were passed over CuO held at 700°C. (Under these conditions, tritium gas and tritiated organic compounds are converted to tritiated water and condense in the trap.) A comparison of the results from the two tests indicates the quantity of tritium released as tritiated water and as other tritiated species.

The results of these tests (Table 4.51) show that tritium was released throughout the 4.5-hr drying period. Although the amount of material released decreased slightly with time, a significant amount of the total tritium release occurred during the last hour of the tests. The data indicated that 37 to 100% of the total quantity of tritium released was in the form of tritiated water.

Table 4.51. Tritium Loss During Drying Period[8]

Sample	Time interval, hr	Loss, % of activity[a] First series	Second series[b]
WH-191	0.5	0.019	0.021
	1.0	0.017	0.018
	1.5	0.015	0.026
	2.5	0.027	0.031
	3.5	0.032	0.020
	4.5	0.24	0.20
	Total from H_2O trap	<0.00	0.006
Total WH-191		0.134	0.142
WH-192	0.5	0.023	0.014
	1.0	0.025	0.031
	1.5	0.026	0.052
	2.5	0.044	0.054
	3.5	0.036	0.054
	4.5	0.022	0.036
	Total from H_2O trap	<0.001	0.010
Total WH-192		0.176	0.251
WH-193	0.5	0.175	0.414
	1.0	0.364	0.521
	1.5	0.342	0.456
	2.5	0.586	0.355
	3.5	0.339	0.269
	4.5	0.245	0.300
	Total from H_2O trap	0.005	<0.001
Total WH-193		2.56	2.32

Table 4.51. continued

Sample	Time interval, hr	Loss, % of activity[a] First series	Second series[b]
WH-194	0.5	0.068	0.060
	1.0	0.103	0.094
	1.5	0.102	0.101
	2.5	0.186	0.106
	3.5	0.135	0.143
	4.5	0.112	0.129
	Total from H_2O trap	0.003	<0.001
Total WH-194		0.709	0.633
WH-195	0.5	0.038	0.155
	1.0	0.137	0.336
	1.5	0.103	0.315
	2.5	0.169	0.502
	3.5	0.159	0.461
	4.5	0.158	0.252
	Total from H_2O trap	<0.001	0.004
Total WH-195		0.760	2.02

[a]Based on manufacturers' analyses of tritium present.
[b]CuO present in furnace for conversion.

4.6.1.4. Tritium Loss at Elevated Temperatures. An investigation was made to determine the amount of tritium released from watch dial paints at temperatures of 50, 100, 150, and 200°C. This range of temperatures was considered representative of heat lamp temperatures to which the paints might be exposed during drying.

The dry paint was weighed out in an alundum combustion boat, and the appropriate amount of binder was added. The sample was then placed in an oven maintained at 50°C for 30 min. During this time, an air stream of 0.8 liter/min was drawn through the oven and through two scrubbers, one containing 50 ml of water, the other 50 ml of toluene. At the end of the 30-min period, a 5-ml sample was removed from each scrubber and counted in a liquid scintillation beta counter. The procedure was repeated for temperatures of 100, 150, and 200°C using the same samples. Additional tests were conducted following the same procedure but using the dry phosphorescent paint without mixing in the binder material. All test results are given in Table 4.52.

Table 4.52. Loss of Tritium at Elevated Temperatures

Sample	Loss, % of activity 50°C	100°C	150°C	200°C
W-H-27-1 (mixed)	0.49	0.26	0.44	1.2
-2 (mixed)	0.12	0.12	0.3	1.1
-2 (dry)	0.05	0.74	1.3	3.5

Table 4.52. continued

Sample	Loss, % of activity 50°C	100°C	150°C	200°C
W-H-28-1 (mixed)	0.34	0.64	2.5	14.1
-2 (mixed)	0.3	1.0	7.	8.5
-2 (dry)	0.03	0.37	1.5	3.4
W-H-29-1 (mixed)	0.19	0.37	0.84	6.9
-2 (mixed)	0.01	0.34	2.	13.
-2 (dry)	0.03	0.39	3.4	7.2
W-H-30-1 (mixed)	0.06	0.33	0.47	3.81
W-H-41-1 (mixed)	0.29	0.18	0.4	0.61
-2 (mixed)	0.15	0.12	0.18	0.54
-2 (dry)	0.14	0.09	0.25	0.48

4.6.1.5. Army Level Vials (Tritium-Activated Phosphor). Army level vials which are illuminated by a tritium-activated (~100 mc) phosphor were examined. The smear technique used by the Army was duplicated (smear taken with filter paper wetted with ethyl alcohol), but the samples were counted with a proportional counter rather than a liquid scintillation counter, which was used by the Army. In all but four cases (Table 4.53) the initial smear blocked the counter. Each source was then soaked in 100 ml of distilled water for 24 hr, and the solution from each was sampled and counted by liquid scintillation techniques. The amounts of activity removed are given in Table 4.53.

Table 4.53. Results of Initial Smear and Water Soak Tests on S-H-99 Sources

Source	Initial smear, dis/min	Tritium removed by water soak, μc	Second smear, dis/min
S-H-99A	a	148	17,024
S-H-99B	34,241	865	18,752
S-H-99C	a	1,257	11,598
S-H-99D	a	1,131	23,040
S-H-99E	a	878	15,784
S-H-99F	78,120	995	37,376
S-H-99G	36,032	608	10,750
S-H-99H	a	851	31,936
S-H-99I	4,400	622	14,376
S-H-99J	a	1,077	19,648
S-H-99K	a	1,099	12,944
S-H-99L	a	This source was disassembled; therefore only initial smear test was performed.	

[a]Blocked counter — probably >100,000 dis/min.

One source was disassembled to determine the method of fabrication. The source consisted of a glass vial containing a liquid with an aluminum trough containing a tritiated phosphor under the vial. The trough and vial were held together by a brass outer casing and plaster of Paris. The phosphor appeared to be tightly adhered to the aluminum, and there was no loose surface material. The origin of the activity is not certain. It may be due to a radiation-induced decomposition of the tritiated polymer used to stimulate light emission from the phosphor. This has not been a serious problem with most watch dial paints; however, these Army units contain ~30 times as much active material as there would be in a comparable volume of typical watch-dial luminous paint.

An air sweep test was performed on two sources. Air at ambient temperature was passed across each source for a period of 1 hr. The air was scrubbed with toluene and water and sampled to determine the amount of tritium removed. Results of these tests are listed in Table 4.54.

Table 4.54. Results of Air Sweep Tests

Source	Total tritium removed, μc
S-H-99A	5.7
S-H-99D	118.0

An opened source (S-H-99E) was placed in a glass tube to which four 1-cm^3 ampules had been attached. The whole system was reduced to a pressure of 40 μ Hg and sealed. One ampule was removed each week for four weeks, and from the known total volume of the system, the total amount of activity released (Table 4.55) was determined.

Table 4.55. Amount of Tritium Released

Week	Total tritium removed, μc
First	7.8
Second	9.8
Third	11.9
Fourth	11.2

The slight discrepancy in the last two values is due to the difficulty in obtaining a precise measurement of the ampule volume.

Two sources (S-H-120A, B) identical to the sources received from the Army were obtained for evaluation. These sources had been coated with a lacquer to prevent leakage. Source S-H-120A was removed from its shipping container

and smeared for transferable activity. The smear counted 704 dis/min. The source was stored in its original shipping container for one week and resmeared. The second smear counted 15,360 dis/min.

As source S-H-120B was being removed from its shipping carton, it was accidentally dropped ~3 ft onto a concrete floor. There was no apparent damage to the source; however, a smear for transferable activity counted 59,904 dis/min. This source was then boiled in water for 1 hr, and 131 μc of tritium was detected in the water at the completion of the test. A subsequent smear was too high to register.

4.6.1.6. Detection of Phosphor Using Ultraviolet Light. During the testing program, smears contaminated with tritium-activated phosphors were examined under an ultraviolet lamp normally used in florescent-dye penetrant inspection techniques. Smear samples were taken using carbon-impregnated black filter paper in an area contaminated with the phosphor, and control samples were taken around the room in which the work was performed.

The tritium phosphor was detected on smears which showed count rates ranging from 64 to >14,000 dis/min, and this type of examination under ultraviolet light was demonstrated to be effective in detecting minute amounts of material which were not detectable by any of the counters used in the ORNL laboratory. In applying this detection method, several precautions should be observed:

a. A dark-colored smear paper must be used since ordinary white smear paper does not provide the color contrast required to detect the phosphor.

b. A quick glance at the object being inspected (smear, hands, etc.) is not sufficient to determine the presence of the phosphor. The "object" must be viewed under the lamp for a sufficiently long period of time (or the observer must wear radiographer's goggles long enough) for the eyes to become accustomed to the low level of light. This time requirement is especially applicable when inspecting the hands. The experiments showed 15 to 20 sec to be an adequate period of time; however, this factor will probably vary from person to person.

c. Other materials found in the area which are not tritium contaminated will also phosphoresce under ultraviolet light. A very rapid inspection will not differentiate between the phosphors and these other materials.

d. The method is not quantitative.

e. Color blind people cannot use this method of detection.

4.6.2. Promethium-147 Dose-Rate Measurements

Dose-rate measurements were made on five samples of ^{147}Pm at varying distances through one or more layers of different absorbers. The samples were prepared in the following manner:

a. Sample W-Pm-94-5. Dry luminous paint containing ^{147}Pm adsorbed on microspheres was mixed with binder according to the manufacturer's specifications. A 0.01-g quantity of the mixture (400 μc) was applied on the surface of an aluminum foil strip as one ~3/8-in.-dia spot.

b. Sample S-Pm-126. A $^{147}PmCl_3$ solution containing 505 μc of ^{147}Pm was evaporated to dryness on a watch glass.

c. Sample S-Pm-127. Same as "b" except it contained 101 μc of ^{147}Pm.

d. Sample W-Pm-94-6. Same as "a" except only 0.005 g of material was used (200 μc ^{147}Pm), and it was applied as separate dots and lines to simulate a 1-in.-dia watch dial.

e. Sample W-Pm-94-7. Same as "d" except a total of 400 μc ^{147}Pm was used to simulate the watch dial.

Measurements were made on each sample at distances of contact, 1 in., 3 in., and 6 in. through air and one or more layers of:

Neoprene rubber glove material (0.025 in. thick, 48.9 mg/cm^2)

Polyethylene plastic glove material (0.0015 in. thick, 3.14 mg/cm^2)

Acetate plastic sheet (0.006 in. thick, 20 mg/cm^2)

White bond paper (0.004 in. thick, 7.9 mg/cm^2).

The following instruments were used to make the measurements:

Cutie Pie, ORNL Model No. 2299-2, paper shell, >1, <1.5 mg/cm^2 window

CD Meter, Anton Electronics, OCDM No. CD-V700 Model 6, 30 mg/cm^2 metal tube

G-M Meter, Nuclear Instrument and Chemical Corp. Model 2610A, ~30 mg/cm^2 glass tube

Beta-gamma Radiation Monitor, ORNL Model No. Q2091, <1.9 mg/cm^2 window. (Measurements of the window thickness on this type of tube by the Instrumentation and Controls Division have shown that they are usually about 0.9 mg/cm^2.)

The values obtained with the Cutie Pie and the Beta-Gamma Radiation Monitor are given in Table 4.56; the values obtained with the CD Meter and G-M Meter were too low to be significant and are not included.

It is expected that a certain number of finished dials would also have to pass the standard soak and bend tests required for tritiated paints. Sample W-Pm-94-5 was tested and lost 1.6% of its activity during the soak test and 0.2% during the bend test. No unusual tendency for promethium salts to "creep" was observed during testing.

Table 4.56. Dose-Rate Measurements on Promethium-147

Distance, in.	Dose Rate, mr/hr									
	W-Pm-94-5, 400 μc		S-Pm-126, 505 μc		S-Pm-127, 101 μc		W-Pm-94-6, 200 μc		W-Pm-94-7, 400 μc	
	Cutie Pie	β-γ monitor	Cutie Pie	β-γ monitor	Cutie Pie	β-γ monitor	Cutie Pie	β-γ monitor	Cutie Pie	β-γ monitor
Unshielded (air)										
Contact	1,900	OS	4,000	OS	820	OS	420	OS	800	OS
1	800	OS	1,350	OS	230	OS	130	OS	215	OS
3	120	OS	150	OS	31	OS	10	OS	32	OS
6	9	16,000	14	22,000	4	4,000	Bkg	2,100	2	3,600
Rubber glove (0.025 in. thick)										
Contact	Bkg	9,000	Bkg	7,500	Bkg	1,350	Bkg	740	Bkg	1,750
1	Bkg	2,200	Bkg	2,000	Bkg	500	Bkg	380	Bkg	540
3	Bkg	620	Bkg	400	Bkg	150	Bkg	175	Bkg	200
6	Bkg	220	Bkg	125	Bkg	Bkg	Bkg	Bkg	Bkg	50
Rubber glove (2 thicknesses)										
Contact	--	7,500	--	3,700	--	700	--	540	--	1,100
1	--	1,750	--	1,300	--	200	--	250	--	400
3	--	380	--	250	--	Bkg	--	Bkg	--	125
6	--	180	--	50	--	Bkg	--	Bkg	--	Bkg
Plastic glove (0.0015 in. thick)										
Contact	1,200	OS	2,300	OS	475	OS	240	OS	440	OS
1	520	OS	875	OS	150	OS	85	OS	130	OS
3	54	OS	110	OS	19	OS	8	19,000	20	OS
6	8	10,000	8	15,000	2	2,900	Bkg	1,450	Bkg	2,150
Plastic glove (2 thicknesses)										
Contact	660	OS	1,200	OS	240	OS	130	OS	240	OS
1	180	OS	520	OS	89	OS	54	OS	88	OS
3	29	OS	59	OS	12	23,500	4	13,500	12	19,000
6	5	8,000	3	5,800	1	1,400	Bkg	640	Bkg	1,100

Table 4.56. continued

Distance, in.	Dose Rate, mr/hr									
	W-Pm-94-5, 400 μc		S-Pm-126, 505 μc		S-Pm-127, 101 μc		W-Pm-94-6, 200 μc		W-Pm-94-7, 400 μc	
	Cutie Pie	β-γ monitor	Cutie Pie	β-γ monitor	Cutie Pie	β-γ monitor	Cutie Pie	β-γ monitor	Cutie Pie	β-γ monitor
Plastic glove (3 thicknesses)										
Contact	390	OS	860	OS	150	OS	84	OS	120	OS
1	96	OS	320	OS	55	OS	30	OS	48	OS
3	20	OS	33	OS	6	17,000	Bkg	6,600	6	8,500
6	4	4,000	Bkg	3,500	Bkg	750	Bkg	420	Bkg	620
Plastic glove (4 thicknesses)										
Contact	210	OS	420	OS	81	OS	48	OS	85	OS
1	25	OS	150	OS	29	OS	18	OS	28	OS
3	6	25,000	19	OS	4	10,000	Bkg	380	4	5,300
6	2	2,000	Bkg	2,000	Bkg	400	Bkg	225	Bkg	320
Plastic sheet (0.006 in. thick)										
Contact	36	OS	78	OS	20	OS	6	OS	14	OS
1	15	OS	39	OS	4	25,000	4	11,500	5	17,000
3	3	7,000	3	7,400	Bkg	1,900	Bkg	820	Bkg	950
6	Bkg	360	Bkg	360	Bkg	50	Bkg	Bkg	Bkg	75
Plastic sheet (2 thicknesses)										
Contact	3	8,000	Bkg	7,000	3	1,550	Bkg	900	Bkg	1,550
1	2	2,800	Bkg	2,000	Bkg	500	Bkg	400	Bkg	600
3	1	700	Bkg	400	Bkg	100	Bkg	Bkg	Bkg	170
6	Bkg	200	Bkg	Bkg	Bkg	Bkg	Bkg	Bkg	Bkg	25
White bond paper (0.004 in. thick)										
Contact	500	OS	1,000	OS	210	OS	140	OS	140	OS
1	85	OS	450	OS	70	OS	37	OS	70	OS
3	25	OS	50	OS	10	22,500	2	8,200	10	15,500
6	4	5,200	Bkg	5,200	Bkg	1,150	Bkg	600	Bkg	820

Table 4.56. continued

Distance, in.	Dose Rate, mr/hr									
	W-Pm-94-5, 400 μc		S-Pm-126, 505 μc		S-Pm-127, 101 μc		W-Pm-94-6, 200 μc		W-Pm-94-7, 400 μc	
	Cutie Pie	β-γ monitor	Cutie Pie	β-γ monitor	Cutie Pie	β-γ monitor	Cutie Pie	β-γ monitor	Cutie Pie	β-γ monitor
White bond paper (2 thicknesses)										
Contact	140	OS	220	OS	49	OS	27	OS	41	OS
1	42	OS	100	OS	16	OS	9	24,000	14	OS
3	6	18,000	10	23,000	3	4,800	Bkg	2,150	4	3,400
6	2	1,250	Bkg	1,000	Bkg	200	Bkg	150	Bkg	150
White bond paper (3 thicknesses)										
Contact	24	OS	41	OS	10	OS	6	23,500	4	OS
1	5	OS	19	OS	4	15,500	2	5,000	Bkg	10,000
3	2	2,500	Bkg	4,300	Bkg	1,000	Bkg	400	Bkg	640
6	Bkg	320	Bkg	250	Bkg	50	Bkg	Bkg	Bkg	25

OS — Off scale; full scale equals 25,000 counts/min.
Bkg — Background.

4.7. Other Sources

4.7.1. Static Charge Elimination Brushes

Four brushes used to eliminate static charges (Fig. 4.76), commonly employed for cleaning photographic negatives, were obtained from the manufacturer. Each brush contained a 0.25- x 2- x 0.007-in. source which was constructed of ^{210}Po sandwiched between silver foils and was positioned in a housing above the bristles. No attempt was made to determine the total activity in the source; however, the brushes are advertised to contain at least 500 μc of ^{210}Po each. (It is understood that the manufacturer is allowed to use up to 1500 μc of ^{210}Po to prolong the useful life of the brush.)

Fig. 4.76. Static Charge Elimination Brush as Received.

The ^{210}Po foils were removed from the open grillwork housing in the brushes for testing. The results are given in Table 4.57. Unless otherwise noted, all smear tests were made with dry filter paper.

Table 4.57. Results of Tests on Polonium-210 Foils

Test	Type of sample	Activity, dis/min			
		S-Po-45A	S-Po-45B	S-Po-45C	S-Po-45D
Moistened smear		--	--	52	60
Wet smear		130	0	26	216
Temperature-humidity[a]	Smear	1484	--	--	--
Temperature-pressure[b]	Smear	--	42	--	--
Vibration[c]	Smear	--	280	--	--
Vibration in water	Smear	--	2545	--	--
	Solution	--	20	--	--
Leach in water	Smear	--	0	--	--
	Solution	--	1479	--	--
Leach in Kodak acid fixer	Smear	--	0	--	--
	Solution	--	98	--	--
Leach in Kodak Microdol X	Smear	--	0	--	--
	Solution	--	2657	--	--

Table 4.57. continued

Test	Type of sample	Activity, dis/min			
		S-Po-45A	S-Po-45B	S-Po-45C	S-Po-45D
Elevated temperature	Smear	5647	--	--	21
	Filter	1544	--	--	226
	Cold trap	150	--	--	0
	Scrubber	250	--	--	0
Saliva	Smear	--	--	--	208
	Saliva	--	--	--	300
Bend 1	Smear	--	--	--	2589
2	Smear	--	--	--	54
3	Smear	--	--	--	96
4	Smear	--	--	--	105
5	Smear	--	--	--	0
6	Smear	--	--	--	0
7	Smear	--	--	--	0
8-16	No smears taken				
17	Smear	--	--	--	21
	Probe	--	--	--	7500
	Edge smear	--	--	--	0

[a]100°C, 100% RH; 0°C, 100% RH.
[b]-60°C, 180 mm Hg; 60°C, 760 mm Hg.
[c]125 cycles/sec for 1 hr.

4.7.2. Americium and Polonium Foils.

4.7.2.1. S-Am-60 and S-Po-61. Five ^{241}Am (S-Am-60A through E) and five ^{210}Po (S-Po-61A through E) sources were obtained for testing. The 1/4- by 4-in. foils were constructed of the active material sandwiched between two silver foils and rolled to a total thickness of 0.007 in. (similar in construction to ^{210}Po foils, Section 4.7.1).

Tests results are given in Table 4.58. Figure 4.77 shows the apparatus for performing the temperature test on these units; Fig. 4.78 shows S-Po-61A after being subjected to a temperature of 850°C.

4.7.2.2. S-Am-131 and S-Po-130. These foils were sectioned into small pieces. Nine foil pieces, each containing ~30 μc of ^{241}Am, were used in the first test series. One foil was placed in each of three separate 25-ml volumes of the following reagents at room temperature: acetone, perchloroethylene, trichloroethylene. The reagents were sampled after 24, 48, and 72 hr. The same procedure was followed using nine polonium foils which each contained ~60 μc of ^{210}Po. No activity was detected in any of the reagents during the tests.

Table 4.58. Results of Tests on ^{241}Am and ^{210}Po Foils

Test	Type of sample	Activity, dis/min									
		S-Am-60-					S-Po-61-				
		A	B	C	D	E	A	B	C	D	E
Smear		283	1,128	354	437	361	--	317	421	198	387
Temperature-pressure[a]	Smear	--	1,770	--	--	--	--	--	--	98	--
Vibration[b]	Smear	--	--	--	--	894	--	--	--	--	2,561
Vibration in water[c]	Smear	--	--	--	--	2,087	--	--	--	--	525
	Solution	--	--	--	--	28,109	--	--	--	--	24,102
Leach in water	Smear	--	--	5,026	--	--	--	60	--	--	--
	Solution	--	--	14,520	--	--	--	3,800	--	--	--
Leach in Kodak acid fixer	Smear	--	--	494	--	--	--	--	--	106	--
	Solution	--	--	19,124	--	--	--	--	--	0	--
Leach in Kodak Microdol X	Smear	--	--	1,692	--	--	--	--	--	512	--
	Solution	--	--	1,612	--	--	--	--	--	1,152	--
Elevated temperature[d]	Smear	192	--	--	--	--	e	--	--	--	--
	Filter	192	--	--	--	--		--	--	--	--
	Cold trap	19	--	--	--	--		--	--	--	--
	Scrubber	96	--	--	--	--		--	--	--	--
Saliva	Smear	--	--	0	--	--	--	--	--	0	--
	Saliva	--	--	52	--	--	--	--	--	67	--
Bend 1	Smear	--	359	--	--	--	--	0	--	--	--
2	Smear	--	283	--	--	--	--	0	--	--	--
3	Smear	--	2,761	--	--	--	--	--	--	--	--
4	Smear	--	2,834	--	--	--	--	16	--	--	--
5	Smear	--	Broke	--	--	--	--	58	--	--	--
6	Smear	--		--	--	--	--	Broke	--	--	--
	Probe	--	1,250	--	--	--	--	0	--	--	--
	Edge smear	--	283	--	5,702[f]	--	--	68	3,682[f]	--	--

[a]-60°C, 180 mm Hg; 60°C, 760 mm Hg.
[b]125 cycles/sec for 1 hr.
[c]In ultrasonic cleaner.
[d]~800°C.
[e]Strip volatilized at 850°C.
[f]Foil cut in two.

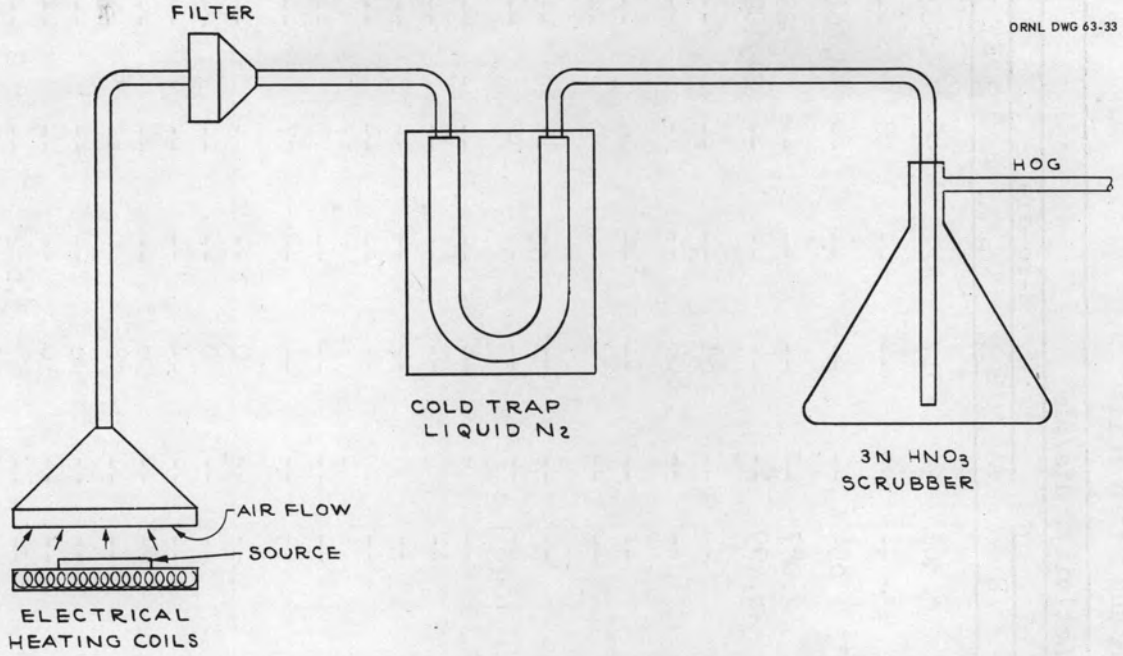

Fig. 4.77. Elevated Temperature Test Apparatus for ^{210}Po Foils.

Fig. 4.78. S-Po-61A After 850°C Temperature Test.

Further tests were conducted to determine the temperature at which activity was evolved. Americium-241 and ^{210}Po foils were sealed individually in evacuated (~50 μ Hg absolute pressure) quartz tubes and heated for 1 hr at temperatures ranging from 600 to 1050°C. In each case the foil contained ~60 μc of activity.

After the measurements were completed, each quartz tube was crushed and counted with alpha and beta counters to verify that all evolved material had been removed and counted.

Test data (Table 4.59) indicate that ^{210}Po foils begin to lose significant quantities of activity at 700°C; ^{241}Am foils at 900°C. As shown in Figs. 4.79 and 4.80, the loss curve for ^{241}Am rises sharply at 900°C and above, but the break point for ^{210}Po foils is not as well defined.

Table 4.59. Activity Loss at Elevated Temperatures for Americium-241 and Polonium-210 Foils

Temperature, °C	Loss, % of activity	
	S-Am-131	S-Po-130
600	0.001	0.002
650	0.002	0.003
700	0.001	0.03
750	0.001	0.005
750	—	0.01
800	0.001	1.3
800	—	0.01
850	0.001	0.045
850	—	0.01
900	0.001	0.23
900	0.006	0.01
950	0.007	0.02
1000	0.015	0.02
1050	0.03	—

One ^{210}Po foil strip was subjected to 800°C for 1 hr in air. Approximately one-half of the original activity was evolved from the foil and caught in the collection points of the system. The strip was then dissolved and assayed to account for the other half of the activity.

4.7.3. Tritiated Foils (Titanium and Zirconium)

Tests on tritium evolution from five tritiated foils (four of titanium, one zirconium) were conducted at temperatures from 200 to 400°C. The titanium foils contained 1, 6, 8, and 15 curies/in.^{2}, the zirconium foil contained 300 mc/in.^{2}. Losses from the titanium foils varied from <0.1% at 200°C to 2.9% at 400°C; the average loss at 400°C was ~0.4%. Tritium losses from zirconium ranged from 4.5 to 19.4%. Data from these tests are given in Table 4.60.

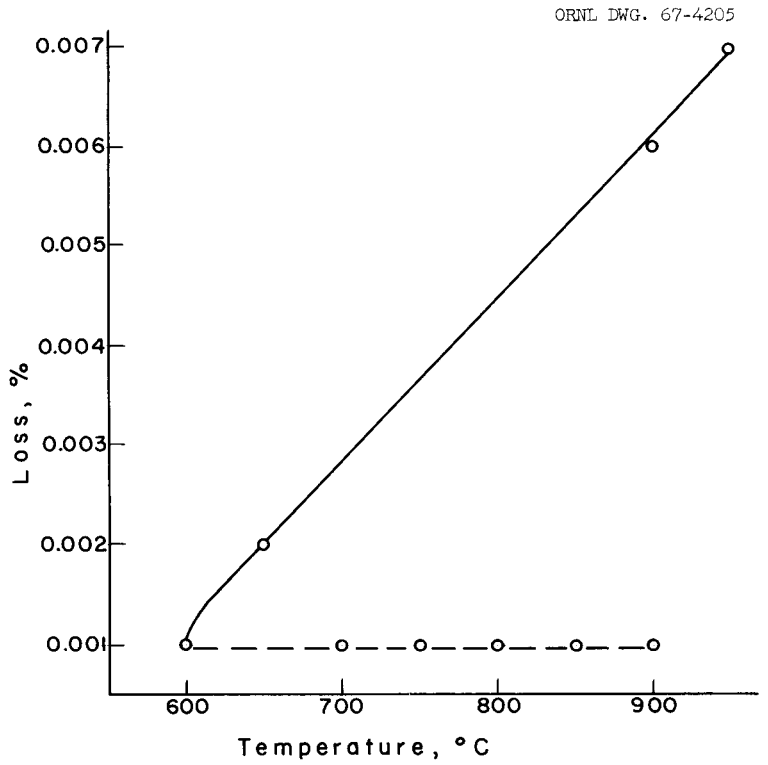

Fig. 4.79. Activity Loss at Elevated Temperatures for Americium-241 Foils.

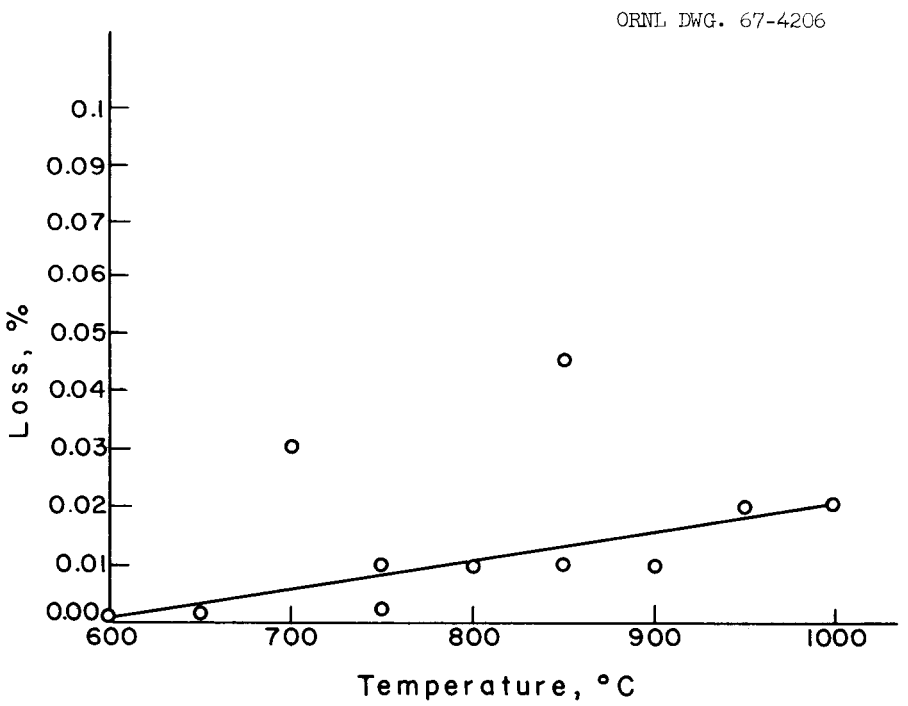

Fig. 4.80. Activity Loss at Elevated Temperatures for Polonium-210 Foils.

Table 4.60. Tritium Loss from Tritiated Foils (Titanium and Zirconium)

Sample	Area, in.^{2}	Activity, curies/in.^{2}	Loss, % of activity					
			150°C	200°C	250°C	300°C	350°C	400°C
S-H-119	0.5	1	0.228	0.197	0.228	0.484	1.03	2.91
S-H-128A	0.5	6	–	0.063	0.061	0.09	–	0.31
S-H-128G	0.5	8	–	0.043	0.045	0.16	–	0.3
S-H-129	0.5	15	–	0.001	0.001	0.002	0.009	0.05
S-H-139	0.25	0.3	–	4.5	11.1	12.6	–	19.4

4.7.4. Annular Cesium Source

S-Cs-80 was an annular source containing loosely packed CsCl powder doubly encapsulated in welded stainless steel. The cylinder was 4-3/4 in. long (ID, 1 in.; OD, 1-1/2 in.) and weighed 375 g. Nine samples of this model were received for testing, and no leaks were detected in the initial leak tests.

Three temperature tests were performed on one sample. The source was heated in air at 1000°F for 24 hr, heated at 1700°F for 1 hr, and subjected to thermal shock by heating to 1700°F and quenching in liquid nitrogen. Leak tests were made at the end of each period, and no evidence of leakage was found.

One source was subjected to an internal pressure test. A small hole was drilled through the cap and a fitting was welded to it. The inside annular wall collapsed at 2500 psig, and the pressure dropped to 0 psig. There were no leaks in the outer capsule at this time. The pressure was raised to 1500 psig at which point the capsule weld ruptured (Fig. 4.81).

Fig. 4.81. Sections of S-Cs-80 Showing Results of Internal Pressure Test.

During structural testing, the source was placed horizontally on a 1/8-in.-dia hardened steel pin and a 375-g weight was dropped on the source from a height of 15 ft. The sample was dented but not punctured (Fig. 4.82), and it did not leak in the vacuum test. When the unit was placed horizontally on a 1-in.-dia piston and impacted with a 12-lb weight dropped from 5 ft, the source was slightly dented but no leaks could be found. When sheared to failure, the sample sheared in two at 21,840 lb of applied force.

Fig. 4.82. S-Cs-80 After Puncture Resistance Test.

One set of three samples was used to classify the source in the ORNL Source Capsule Classification System. The source was not damaged by any of the Class C temperature tests, and no leaks could be found after this series of tests.

When a sample was heated in air to 2550°F for 1 hr,* the wall of the inside capsule collapsed from internal pressure buildup. The surface of the capsule was badly oxidized, and the capsule weld was completely burned off. Following a Class D Thermal Shock Resistance test, a microscopic examination of the source capsule disclosed no cracks in the capsule or its welds, and a vacuum test showed no evidence of leaks.

Other than slight flattening (1/8 to 9/32 in.) or indentation (0.075 in.), Class III structural tests did not damage the source, no cracks developed in the welds or the capsules, and the capsules did not leak in the vacuum leak tests made after these tests. S-Cs-80 was classified as C-III.

4.7.5. Cylindrical Cobalt Source

Six samples of S-Co-82 were obtained for the testing program. This source was a cylindrical rod 1/2 in. in dia by 12 in. in length containing cobalt pellets doubly encapsulated in welded stainless steel. The ~6-in.-long inner capsule was positioned in the center of the source by lead plugs (~3 in. long) placed in either end of the outer capsule. The assembled source weighed 250 g.

When one source was subjected to a temperature of 1700°F for ~15 min, the lead plugs melted and built up enough pressure to blow out the end of the outer capsule (Fig. 4.83). The inner capsule, however, remained intact and did not leak when subjected to a vacuum leak test. A second sample was subjected to a temperature of 1000°F for 24 hr. This source did not show evidence of a leak at the end of the period, and the unit was then placed

*Class D Maximum Temperature Resistance test is now 2400°F for 1 hr.

in a furnace at 1700°F for 1 hr. In this case, no rupture occurred although it was obvious that the lead had melted. The source did not leak in the vacuum leak test.

Fig. 4.83. S-Co-82A After High Temperature Test (1700°F for 15 min).

One source was heated at 750°F for 1 hr, was held at a temperature of -76°F for 24 hr, and heated to 212°F for 24 hr. Vacuum leak tests after each period disclosed no leaks, and no damage to the capsule was evident.

Three samples were subjected to impact tests. One source was placed horizontally on a 1-in.-dia piston and a 6-lb weight was dropped from a height of 12 ft to strike the source. Only slight denting of the capsule was noted, and the unit did not leak. In the other impact tests, the source was placed horizontally on a flat surface. A 15-lb weight dropped from a height of 8 ft flattened the capsule in the area of impact to 0.387 in.; a 12-lb weight from 5 ft flattened it to 0.460 in. A 12-lb weight dropped from 5 ft onto the weld area flattened the capsule to 0.475 in.; however, none of the capsules leaked after any of these tests.

In shear tests, 1000 lb of force for 1 hr produced only slight indentation, and 7488 lb of force was required to shear the capsule in two.

For the puncture tests, a sample was placed horizontally on a 1/8-in.-dia hardened steel pin. A 250-g weight dropped from a height of 15 ft dented the source ~0.06 in.; a 750-g weight from 5 ft dented it 0.08 in. There was no penetration, and leak tests showed no evidence of leaks.

4.7.6. Irradiator Bar (S-Cs-136)

Three inactive sources of this type were obtained for testing. The source was a rectangular bar (3/8 x 1-1/8 x 13-5/16 in.) doubly encapsulated in stainless steel with welded closure. S-Cs-136 was classified as C-III based on the test results which are shown in Table 4.61.

Table 4.61. Test Results on S-Cs-136

Source	Class	Type of test	Results
A	C	Maximum Temperature Resistance	No leaks
	C	Operating Temperature Resistance	
		High	No leaks
		Low	No leaks
	C	Thermal Shock Resistance	No leaks
	II	Puncture Resistance	No leaks, indented 3/32 in.
	III	Impact Force Resistance	No leaks
	III	Resistance to Crushing	No leaks
B	III	Resistance to Shear	No leaks, slight indentation
	III	Puncture Resistance	Punctured
		Sheared to failure	Sheared at 3800 lb of force
C	Not tested		

4.7.7. S-B-168

Three inactive sources of this type were used in the testing program. The source had a soldered brass body in a stepped-cylinder geometry. The source end of the capsule was 1/4 in. in dia by 1/4 in. in length and it had a 1/16-in.-high base (1/2 in. in dia). The sources were subjected to the ORNL classification tests as shown in Table 4.62 but they were not given a classification.

Table 4.62. Test Results on S-B-168

Source	Class	Type of test	Results
A	B	Maximum Temperature Resistance	Soft solder melted; however, it resolidified in cooling in the vacuum leak test and did not show a leak
B	A	Operating Temperature Resistance	
		Low	No leaks
		High	No leaks
	A	Thermal Shock Resistance	No leaks
	A	Maximum Temperature Resistance	No leaks
	II	Resistance to Crushing	No leaks, bent base
	II	Impact Force Resistance	Source badly crushed, leaked

Table 4.62. continued

Source	Class	Type of test	Results
C	IV	Puncture Resistance	No leaks
	V	Puncture Resistance	No leaks
	III	Resistance to Crushing	Capsule collapsed and leaked

4.7.8. S-B-169, S-B-170, and S-B-171

Three inactive sources of each of these types were obtained for testing. These sources were disks 1 in. in dia by 3/8 in. thick; S-B-169 and S-B-171 were of aluminum, S-B-170 of stainless steel. The source is made by drilling a 1/4-in.-dia by 1/4-in.-deep hole in the disk and inserting a plug. The plugs in S-B-169 and S-B-170 were soldered in place, S-B-171 was welded. Results of the test program on these sources are given in Table 4.63.

Table 4.63. Test Results on S-B-169, S-B-170, and S-B-171

Source	Class	Type of test	Results
S-B-169A	B	Maximum Temperature Resistance	Solder melted
S-B-169B	A	Operating Temperature Resistance	
		Low	No leaks
		High	No leaks
	A	Thermal Shock Resistance	No leaks
	A	Maximum Temperature Resistance	No leaks
	III	Resistance to Crushing	Mashed in on both sides; however, no leaks
	IV	Resistance to Crushing	Crack in solder, leaked
S-B-169C	IV	Puncture Resistance	No leaks
	V	Puncture Resistance	Indentation, no leaks
	II	Impact Force Resistance	Solder cracked, leaked
S-B-170A	C	Maximum Temperature Resistance	Solder melted
S-B-170B	B	Maximum Temperature Resistance	No leaks
	B	Operating Temperature Resistance	
		High	No leaks
		Low	No leaks
	B	Thermal Shock Resistance	No leaks
	II	Resistance to Crushing	No leaks

Table 4.63. continued

Source	Class	Type of test	Results
S-B-170C	V	Puncture Resistance	No leaks
	III	Impact Force Resistance	Edges slightly dented, no leaks
	IV	Resistance to Crushing	Solder cracked, leaked
S-B-171A	B	Maximum Temperature Resistance	No leaks
	B	Operating Temperature Resistance	
		High	No leaks
		Low	No leaks
	B	Thermal Shock Resistance	No leaks
	II	Resistance to Crushing	No leaks
S-B-171B	II	Impact Force Resistance	Edges of source dented, no leaks
	III	Impact Force Resistance	Weld cracked, leaked
S-B-171C	III	Resistance to Crushing	Edges dented, no leaks
	V	Puncture Resistance	Slight indentation, no leaks
	IV	Resistance to Crushing	Weld cracked, leaked

S-B-169 and S-B-170 were not given a classification; S-B-171 was classified as B-II.

4.7.9. U. S. Army Lensatic Compasses

A set of eight U. S. Army lensatic compasses (Fig. 4.84), each containing 75 mc of tritiated phosphor paint, was subjected to smear, water-leach, and temperature-humidity tests. The smear tests (Table 4.64) revealed moderate contamination (608 to 29,000 dis/min) of the compass surfaces and carrying cases. Smears of exposed paint areas showed these areas to be highly contaminated (9,810 to 546,000 dis/min). The amount of transferable activity did not change appreciably as a result of exposure to a temperature-humidity test. Compasses exposed to the standard 24-hr water-leach test lost an average of 5.66×10^7 dis/min or 0.29% of the initial activity.

When the screw posts (Fig. 4.85, areas 4 and 7) were examined under a microscope, it was noted that the appearance of the phosphor bed differed considerably among compasses. In several compasses, a depression in the center of the phosphor bed almost extended to the bottom of the bed. Smears indicated that these areas did not have effective containment of tritium.

Fig. 4.84. U. S. Army Lensatic Compass as Received.

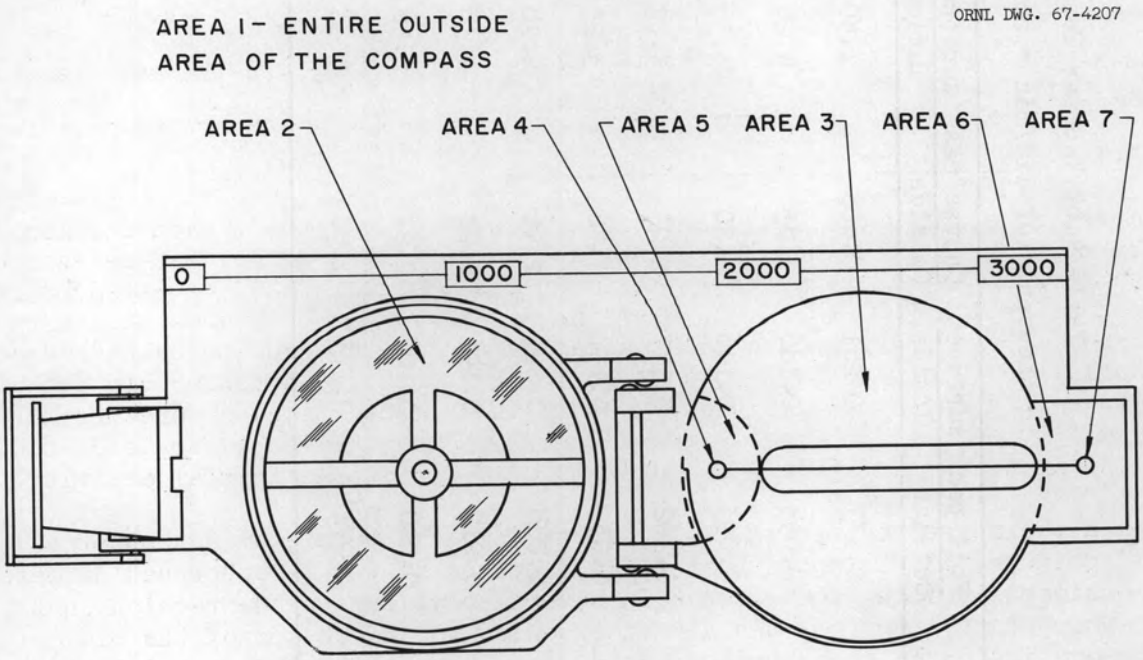

Fig. 4.85. Schematic of U. S. Army Lensatic Compass.

Table 4.64. Smear Test Results of U. S. Army Compasses

(in thousands of dis/min — obtained by liquid scintillation counting)

Compass	Foil pack surface		Canvas case surface		Compass surface						
	Outside	Inside	Outside	Inside	1	2	3	4	5	6	7
A	0.137	0.261	0.608	1.40	0.491	2.26	0.845	39.9	1.28	0.784	73.4
B	0.053	0.186	1.83	4.20	1.17	4.60	0.909	62.2	1.33	2.13	546.0
C	0.093	0.146	1.20	3.36	2.20	12.4	2.66	250.0	29.0	1.94	262.0
D	0.102	0.177	2.27	5.07	5.38	5.15	2.53	44.6	1.42	0.848	11.8
E	0.039	0.150	1.46	3.23	3.07	27.9	2.96	246.0	2.96	1.47	107.0
F	0.088	0.221	2.96	5.28	6.14	14.8	2.25	9.81	1.30	1.38	198.0
G	0.012	0.141	2.28	4.18	9.14	17.6	3.19	248.0	2.91	2.13	149.0
H	0.040	0.105	2.27	2.58	5.77	5.18	2.78	110.0	0.294	4.64	103.0
Average	0.071	0.173	1.86	3.66	4.17	11.2	2.27	126.3	5.06	1.91	181.3

4.7.9.1. Smear Tests. Each foil pack shipping container was smeared with Whatman 50 filter paper (4.25 cm dia). Forty-five percent of the outside surface area was smeared with filter paper with pressure of a 4.5-lb weight resting on a 0.833-in.-dia sponge-rubber disk. A second smear was taken of the inside surface. Each canvas case was smeared on the inside and outside surface with filter paper using moderate pressure.

Selected areas (Fig. 4.85) of the compasses were smeared in various ways: areas 1, 2, and 3 were smeared with filter paper; areas 4, 5, 6, and 7 were smeared with cotton-tipped applicators. The smear samples (both filter paper and cotton-tipped applicators) were counted using a liquid scintillation spectrometer. Blank samples containing filter paper and cotton-tipped applicator with no activity were counted with each group of samples. Control samples prepared in the same manner but containing known amounts of tritiated biphenyl toluene were also counted with each group of samples.

Beta scintillation counting was compared with gas flow counting using two sets of smears taken from area 2 of compass E. Carbon-impregnated Whatman 50 filter paper was used for gas flow counting. The filter papers were mounted on 0.875-in.-dia rubber pads cemented to a wooden block in such a way that when the block was rotated 180° each type of filter paper would smear half of area 2 without overlapping. The carbon-impregnated smear counted 276 dis/min on the gas flow counter. The filter paper smear counted 9.54×10^3 dis/min on the beta liquid scintillation counter. In a similar test with a double pass on each smear, the gas flow analysis was 1.28×10^3 dis/min and the beta liquid scintillation analysis was 1.04×10^4 dis/min.

Compass H was partly decontaminated by cleaning the exposed surfaces with cotton-tipped applicators dipped in soapy water and rinsing with applicators dipped in clear water. (The paint in the screw holes was protected from water.) The compass was then smeared and exposed to air. After 30 days, the compass was smeared again using the same techniques as were used in the initial smear tests except that the screw holes (areas 4 and 7) were not smeared. Since the results of these tests were lower than expected, the source was retested to verify the results. The results are given in Table 4.65.

Table 4.65. Results of Smear Tests on Decontaminated Compass

Smear test	Smear, dis/min				
	Area 1	Area 2	Area 3	Area 5	Area 6
	$\times 10^3$	$\times 10^3$	$\times 10^3$	$\times 10^3$	$\times 10^3$
Initial test	5.77	5.18	2.78	0.294	4.64
After decontamination	1.77	1.34	1.36	1.22	0.77
After 30 days in air	0.206	0.488	0.059	0.494	0.418
Retest	0.726	0.732	0.349	0.888	0.432

4.7.9.2. Temperature-Humidity Test. Two compasses (C and F), chosen because compass C had a deeper impression in the paint in the screw hole than compass F, were placed in an environmental chamber and subjected, in succession, to the following conditions: 16 hr at 120°F–80% relative humidity, 8 hr at 32°F–5% relative humidity, and 16 hr at 120°F–80% relative humidity. Both compasses were then smeared with filter paper and cotton-tipped applicators. The results are given in Table 4.66.

Table 4.66. Results of Smear Tests on Compass Surfaces

Compass	Smear, dis/min						
	Area 1	Area 2	Area 3	Area 4	Area 5	Area 6	Area 7
	$\times 10^3$	$\times 10^3$	$\times 10^3$	$\times 10^3$	$\times 10^3$	$\times 10^3$	$\times 10^3$
C	4.79	6.12	1.08	349	601	1.60	1.75
F	2.20	12.3	1.46	15.5	1.66	3.88	46.4

4.7.9.3. Water-Leach Test. Two compasses (A and B) were immersed in 100 ml of distilled water for 24 hr. Compass A had a deep hole in the center of the paint in the screw hole. Analysis of the leach water by beta scintillation showed that the total activity leached from compass A and compass B was 5.17×10^7 and 6.14×10^7 dis/min, respectively.

A similar leach test was performed on compasses D and G. In this case, the hinges were removed from the compasses so that each half of the compass could be leached separately. For compasses D and G, the halves which contained area 2 had leach rates of 6.02×10^7 and 5.40×10^7 dis/min, respectively. The compass halves containing area 3 had leach rates of 0.905×10^7 and 1.36×10^7 dis/min, respectively.

4.7.10. Strontium Source (Submitted for Examination)

Source S-Sr-98 was sent to ORNL for examination in the testing program. The date of manufacture was not known; however, the source originally contained 30 μc of ^{90}Sr. The unit was ~5 x 1/2 x 1/8 in., and the strontium was contained in a machined depression (~1/4 in. in dia) which had a mica window glued over the top. When received, the mica was bulged out on one edge leaving a crack. The source leaked in the area of the crack during vacuum leak testing.

4.7.11. Returned Sources

4.7.11.1. S-Cs-138. A "leaking" $^{137}CsCl$ source made at ORNL was returned for inspection. Although one area of the weld appeared rough, no leak was found using the vacuum leak test method; and X rays of the area showed no noticeable irregularities. A piece of Type AA X-ray film was placed on top of the source for 20 hr. When the film was developed, a darkened spot was found which indicated that a small piece of the cesium might have lodged in the weld and could have caused the high smear count.

Portions of the weld material (~3-5 mils) were removed from the source by abrasion, and the film exposure test was repeated. When a comparison was made of four exposures, it was evident that active material had been trapped in the weld itself. It was concluded that the "source leak" was the release of some of this material from the weld.

4.7.11.2. S-Sr-125. A special $^{90}SrTiO_3$ source (containing stainless steel windows 2 mils thick) manufactured by ORNL swelled during the one-week shelf-life test. Although the source did not leak, it was retained for testing. Measurements indicated a pressure of ~15 psig had built up in the capsule. Analysis of a gas sample taken from the container showed 82.23% H_2, 0.86% CH_4, 0.37% H_2O, 0.03% other hydrocarbons, 1.25% N_2 + CO, 0.16% O_2, 14.77% Ar, and 0.33% CO_2. It was theorized that grease or oil contamination was sealed in the capsule during assembly and that this material deteriorated during the shelf-life test. Two identical sources showed no evidence of swelling.

4.7.12. Sources Received for Burial.

4.7.12.1. S-Co-95. This was a solid brass annular source (OD, 2-3/8 in.; ID, 1.375 in.; length, 4-17/32 in.). The annular space contained 11 source holders, each with a threaded plug which was back soldered when filled. The source was manufactured in 1949 and originally contained 600 curies of ^{60}Co. The only test made was to remove a portion of the brass capsule and submit it to the metallurgical laboratory for macroscopic examination. No deterioration or damage to the source capsule was found as a result of its prolonged usage and exposure to radiation.

4.7.12.2. S-Co-116. When S-Co-116 was received for burial, it had an activity of 100 curies. The date of manufacture, the amount of ^{60}Co originally contained, and the reason for burial were not known. The source was sectioned, the cobalt was removed, and the capsule was decontaminated with soap and water to ~10 mc/hr. Macroscopic examination in the metallurgical laboratory did not indicate any damage to the source capsule material or to its closure as a result of prolonged exposure to irradiation. No further tests were conducted on this source.

5. TESTING OF PROTOTYPE SOURCES

5.1. Ice Detector Probe and Source for Use on Airplanes

The integrity of both the complete ice detector probe and the source used in the probe (Fig. 5.1) was tested by subjecting five samples of each unit to the specific requirements of the ORNL Source Capsule Classification System. In these tests, the sources were designated as G-Sr-172A through E; the assembled probes as P-172-A through E. Each source contained 50 μc ^{90}Sr, singly encapsulated in a stainless steel container. The thin window was soldered to the source body, and the enclosure plug was fusion welded in place.

Fig. 5.1. Ice Detector Probe as Received.

5.1.1. Sources

5.1.1.1. Initial Tests. Except for two sources, initial smear tests and vacuum leak tests gave negative results. G-Sr-172A did show 100 dis/min on the smear test; however, the vacuum leak test did not indicate any leaks. Source G-Sr-172E leaked in the initial vacuum leak test, but the smear test did not indicate any transferable activity.

5.1.1.2. Temperature Tests. After the initial tests, source G-Sr-172A was placed in a furnace at 400°F for 1 hr (Class A Maximum Temperature Resistance test). A subsequent wipe test indicated that no activity was present on the outside surface of the source, and the vacuum leak test disclosed no leaks. The source was then heated to 200°F, quenched in ice water, and cooled to -76°F (Class A Thermal Shock Resistance test). There was no visible damage, and the vacuum leak test and smear test were negative.

Source G-Sr-172B was subjected to a Class A Operating Temperature Resistance test by placing the source in air in an environmental chamber at 32°F for a period of 24 hr and then again in the same chamber at 212°F for another 24 hr. At the end of each of these periods, the source was smeared for transferable activity and was vacuum leak tested. The results were negative for all tests.

The Class B Maximum Temperature Resistance test was performed on G-Sr-172D by placing the source in a furnace at 750°F for 1 hr. When removed from the furnace, the source smeared 50 dis/min; however, the vacuum leak test did not indicate a leak. The source was then sealed in a quartz tube and heated to 1700°F for 1 hr (Class C Maximum Temperature Resistance test). During this test, the source separated at the point where the window was soldered to the source body (Fig. 5.2).

Fig. 5.2. G-Sr-172 After Class C Maximum Temperature Resistance Test.

5.1.1.3. Structural Tests. G-Sr-172C was used for the structural tests. The source was first placed on its edge, and 200 lb of force was applied for 30 min (Class I Resistance to Crushing test). No visible damage was detected, and tests indicated no transferable activity or leaks.

The source was then placed, thin window down, on a 1/8-in.-dia pin and a 20-g weight was dropped from 6 in. onto the source (Class I Puncture Resistance test). A slight indentation in the window resulted, but subsequent smear and leak tests indicated that capsule integrity had been maintained.

The Class I Impact Force Resistance test was performed by placing the source on its edge and dropping a 4-lb weight from 5 ft onto the source. This action caused the capsule to collapse and ruptured the thin window.

5.1.2. Probes

All probes were assembled according to instructions on the manufacturer's drawings; however, only two units contained actual sources (source G-Sr-172A was sealed in probe P-172-A and G-Sr-172B in P-172-B). Only one of the completed assemblies (P-172-D) leaked during the initial vacuum leak tests.

5.1.2.1. Temperature Tests. The P-172-A assembly was placed in a furnace at 750°F for 1 hr (Class B Maximum Temperature Resistance test). Upon inspection, a blister was observed where the zinc chromate primer-sealant had boiled out around the threads of the plug closure of the probe. No transferable activity was found on the probe, but the vacuum leak test indicated a leak in the blister area.

This assembly was next immersed in liquid nitrogen for 24 hr, then heated to 500°F for 24 hr (Class C Operating Temperature Resistance test). At the end of each 24-hr period, the assembly was visually inspected, smeared to detect transferable activity, and vacuum leak tested. No visible damage was observed and no transferable activity was found; however, the assembly continued to leak in the same area where the blister was noted after the Class B Maximum Temperature Resistance test.

The Class C Thermal Shock Resistance test was performed using probe P-172-B. The assembly was heated in a furnace to 500°F, removed and immediately plunged into ice water for ~10 sec, then placed in an atmosphere of -76°F and held for 15 min. Visual examination of the probe showed a blistering of the primer-sealant at the threads of the plug (similar to the action observed with P-172-A), and a vacuum leak test indicated a leak in the assembly at this point. A smear test was negative for transferable activity.

The P-172-B assembly was next subjected to the temperature-altitude test outlined in §30.24 (j) (v) (a) Title 10 Code of Federal Regulations, Part 30. At the end of this test no damage to the source assembly was visible, and no transferable activity was found.

Class A Maximum Temperature Resistance and Class B Maximum Temperature Resistance tests were applied to probe P-172-C. After 1 hr in a furnace at 400°F, no leaks were indicated by the vacuum leak test; however, after 1 hr in the furnace at 750°F, a blister similar to the ones noted on probes P-172-A and P-172-B appeared on the surface of the threads. The probe also leaked at the site of this blister during the vacuum leak test.

In an effort to determine whether moisture in the primer-sealant might be causing the blistering which had been observed, P-172-C was "baked out" in a furnace at 100°C for 12 hr. A vacuum leak test at the end of this period did not indicate any leaks.

The Class A Maximum Temperature Resistance test was then repeated using this probe. After 1 hr in a furnace at 400°F, a large blister of the zinc chromate primer-sealant formed on the surface of the threads, and this blister leaked badly in the vacuum leak test. The probe was disassembled,

the threads were cleaned, and the unit was reassembled. It still leaked. Even after the probe had been disassembled for a second time, a dummy source had been inserted, and the unit been reassembled, the assembly continued to leak in the vacuum leak test.

5.1.2.2. Structural Tests. After being used in the Thermal Shock Resistance test, P-172-B was placed on its side with the source end resting on a 1/8-in.-dia pin, and an 1100-g weight was dropped onto it from a height of 3 ft (Class III Puncture Resistance test). An indentation of ~1/16 in. was made on the probe, but the assembly was not punctured. A smear counted only a background level of activity.

The Class II Resistance to Crushing test was then performed by placing the probe in a hydraulic press and applying a 200-lb force to the head of the assembly for 1 hr. Even after being subjected to an additional force of 2000 lb for a 1-hr period (Class III Resistance to Crushing test), the assembly still sustained no damage and no transferable activity was indicated.

When probe P-172-D was being assembled for structural testing, a blister similar to those formed during previous temperature tests occurred while the plug was being screwed into the assembly. The probe was disassembled and the zinc chromate primer-sealant was found to be wet below the second thread. The plug and threads were cleaned and the unit reassembled, but the probe still leaked badly in the vacuum test.

Probe P-172-D was, however, used for the Class III Impact Force Resistance test. When a 10-lb weight was dropped from 6 ft onto the side of the probe head, the probe cracked on both sides of the head in the threads (Fig. 5.3). The assembly was then placed in the shear blocks and force was applied. At a 40-lb force (less than Class I), the probe broke just below the source capsule cavity. The break occurred far enough below the cracks in the threads to indicate that this condition had had little or no effect on the break (Fig. 5.4).

In the Class II Impact Force Resistance test on P-172-E, a 10-lb weight dropped from 3 ft onto the side of the probe cracked both sides of the capsule.

5.2. Cerium Ring Sources

This source, designed for use in detection of faulty drilling operations in the production of automobile motor blocks, was fabricated from stainless steel in the shape of a ring (OD, 1.375 in.; ID, 1.283 in.; height, 0.375 in.). Figure 5.5 shows the structural features of the source and the manner in which the parts were assembled (the activity is plated only on the outside of Part 15).

Four sources were received from the vendor. Three assemblies (S-Ce-198A, S-Ce-198B, and S-Ce-198C) were standard production sources containing 6, 7, and 0.8 μc of ^{144}Ce-Pr, respectively; the fourth source was unassembled and contained no activity. (This last unit was provided so structural features could be easily observed.)

Fig. 5.3. Ice Detector Probe After Class III Impact Force Resistance Test.

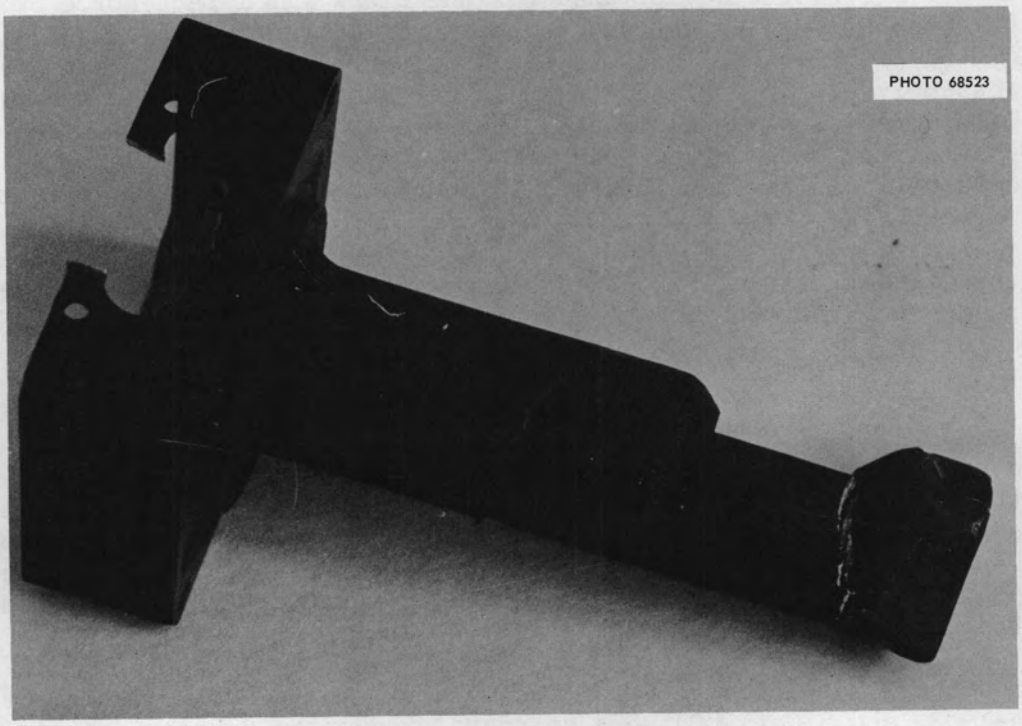

Fig. 5.4. Ice Detector Probe After Resistance to Shear Test.

ORNL DWG. 67-4208

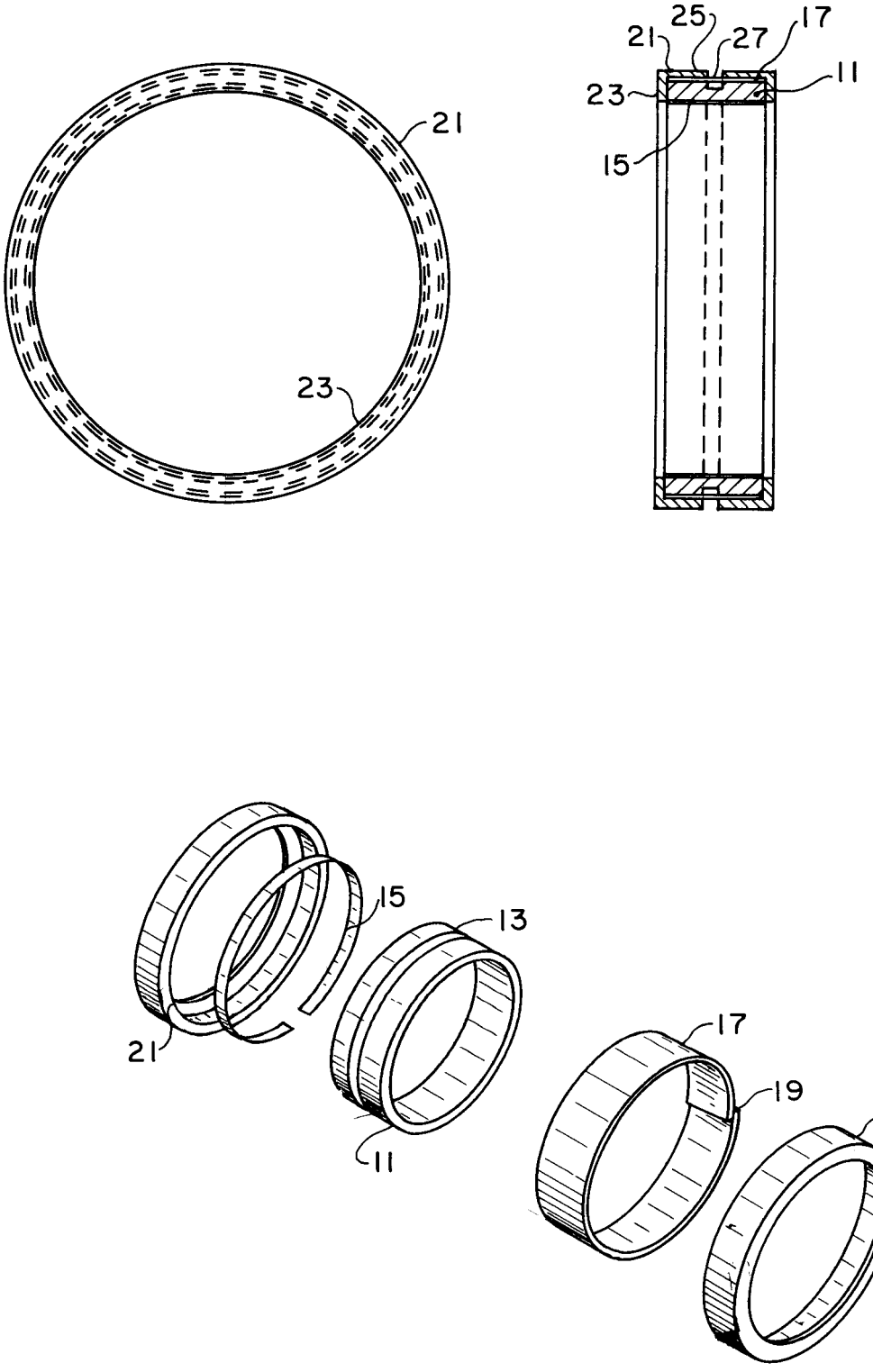

Fig. 5.5. Schematic of Cerium Ring Source.

Source S-Ce-198A was tested to obtain information concerning the temperature and structural integrity of the source so it might be classified under the ORNL Source Capsule Classification System. Class B-III was chosen because of the temperature limitations found and the structural qualities observed. The smear test and the 24-hr distilled-water leach test were used to establish evidence of source failure.

5.2.1. Initial Tests

The three complete assemblies were subjected to smear tests and 24-hr distilled-water leach tests. All results were negative for transferable contamination and activity. The initial count on source S-Ce-198A, determined by using an end-window GM tube and ultrascaler, was 676,480 dis/min.

5.2.2. Temperature Tests

S-Ce-198A was subjected to the Class B Maximum Temperature Resistance test (750°F for 1 hr). The heat caused discoloration, but no other damage was visible. The source did not smear, and no activity was detected in the 24-hr distilled-water leach test. This unit was then subjected to 1700°F for 1 hr (Class C Maximum Temperature Resistance test). This test caused additional discoloration but no visible damage; however, the source smeared 700 dis/min. The leach water after 48-hr leaching in 20 ml of distilled water was free of activity. The total count on the source after this testing was 671,247 dis/min.

The Class B Operating Temperature Resistance test (-40°F for 24 hr, then 212°F for 24 hr) was performed using S-Ce-198B. Smear tests did not reveal any transferable activity, and the leach test in 25 ml of distilled water for 72 hr showed no activity.

This source was next subjected to the Class B Temperature-Humidity Cycling Resistance test (200°F—95% RH to 35°F—5% RH, 8-hr cycle time for 48 hr). During this test, the environmental test chamber did not cool rapidly enough to keep pace with the programmer; consequently, the minimum temperature reached was only 60°F instead of 35°F. Smear tests were made both before and after a 24-hr leach test in 25 ml of distilled water. No activity was found in any of these tests.

When S-Ce-198B was given the Class B Thermal Shock Resistance test (212°F to 0°F then to -70°F), the smear test revealed 1700 dis/min transferable activity; however, no activity was found in a 24-hr distilled-water leach test. Since S-Ce-198B had failed the Class B Thermal Shock Resistance test, the test was repeated with S-Ce-198C as required by the test procedure. S-Ce-198C passed the test.

5.2.3. Structural Tests

Only one structural test was performed on S-Ce-198A. A 6-lb weight was dropped from a height of 5 ft onto the source, which was positioned at its lowest center of gravity (Class II Impact Force Resistance test). This action caused a slight denting of the edges and distorted the inner

ring, but the source remained intact. A smear test followed by a 24-hr leach test in distilled water did not reveal any transferable activity.

Source S-Ce-198C was used for the Class III External Pressure Resistance test. The unit was placed inside a water-filled pressure vessel, and 1000 psig was applied for 15 min. No visual damage was noted, and the smear test indicated that no activity was released. This source was then exposed to the Class III Resistance to Crushing test by placing the source in an upright position (position of highest center of gravity) and applying a 1000-lb vertical force for 1 hr. Upon application of the force, the source immediately flattened; however, smear tests of all exposed surfaces taken at the end of the period did not reveal any activity.

The Class III Resistance to Shear test was completed by placing this source in the shear blocks and applying a 1000-lb force for 1 hr. Only minor visible damage to the source was noted, and no transferable activity was found with the smear test.

For the Class III Puncture Resistance test, S-Ce-198C was placed with the flat side resting on a 1/8-in.-dia pin and a 50-g weight was dropped on it from a height of 3 ft. This test caused only slight visible damage to the source; no activity was found with the smear test. Similarly only minor visible damage resulted when a 12-lb weight was dropped onto the source from a height of 5 ft (Class III Impact Force Resistance test), and the smear test and the 24-hr distilled-water leach test did not reveal any activity. Figure 5.6 shows S-Ce-198C at the end of the test period.

Fig. 5.6. S-Ce-198C After Completion of Test Sequence.

5.2.4. Cross-Sectional Examination

During initial examination of the sources, microscopic examination of source S-Ce-198C indicated that the source parts were bound together and, very likely, sealed with what appeared to be an epoxy resin. After testing was completed, S-Ce-198A was disassembled by making a transverse cut through the rings and prying the sections apart. The parts were counted separately and most of the activity was found on the small ribbon (Part 15, Fig. 5.5). The parts were next placed in a beaker of distilled water for three days. Two samples were taken of the leach water — one of the undisturbed water and one after vigorous agitation of the beaker. Both samples were free of activity.

S-Ce-198C was also cut open and it was determined that a hard plastic material, presumed to be an epoxy resin, had been used to hold the parts together. The structural tests had obviously broken loose any epoxy seal which might have existed, yet no activity was found on any of the smear tests or in the water leach test. The window (Part 17) and the inner ring (Part 13) were cemented together with a continuous layer of epoxy to help contain the activity. The outer rings (Parts 21) were not sealed but were cemented to the window in small areas to hold the source parts together.

5.3. Sources for X-Ray Unit

Twelve prototype sources for use in a portable X-ray unit were tested for containment integrity according to the requirements of the Source Capsule Classification System. Four samples of three source models were obtained from the vendor and coded:

S-SS-163A S-SS-163B	S-SS-163C S-SS-163D	stainless steel outer capsule and plug
S-SS-164A S-SS-164B	S-SS-164C S-SS-164D	aluminum capsule with stainless steel plug
S-SS-165A S-SS-165B	S-SS-165C S-SS-165D	aluminum capsule with stainless steel plug

To provide a method for leak detection during testing, each source contained ~12 mg of KCl incorporated into a dummy source pellet.

5.3.1. Test Procedure

5.3.1.1. Leak Test. For the initial leak test, each source was rinsed in acetone, washed in distilled water, and placed in 25 ml of doubly distilled water. A 10-ml aliquot was then withdrawn to be used as the control sample. After the source had soaked for 10 min in the remaining 15 ml of water, the pressure above the water was reduced to 5 in. Hg absolute and held for 30 sec; then the equipment was vented to atmosphere for 5 min. After this vacuum-venting procedure had been repeated five times, the 15 ml of water was used as the test sample.

5.3.1.2. Temperature and Structural Tests. Each source was subjected to one or more temperature and structural tests under test conditions corresponding to the values of the ORNL Source Capsule Classification System. After each test, the leak test procedure was followed except that the 10-ml control sample aliquot was taken before the source was immersed in the water.

5.3.2. Sample Analysis

The leak-test water samples were analyzed by a flame photometric technique according to a routine and standardized ORNL Analytical Chemistry Division laboratory procedure. For potassium in the concentration range of interest (>0.01 μg/ml), the precision of the method is ±2% at the 95% confidence level.

5.3.3. Results

Table 5.1 gives the results of tests on these 12 sources. In each case, "A" is the control sample and "B" is the leak test sample.

After classification testing, one source of each type was immersed in dye penetrant, subjected to the leak test procedure, allowed to dry, and then disassembled. In all three cases, dye was found in the inner cavity which indicated that the seal was not effective. Figures 5.7 and 5.8 show the penetration of dye into the inner cavity. The "dark" spots on the units are the dye.

Fig. 5.7. Disassembled X-Ray Unit Source Showing Dye Penetrations.

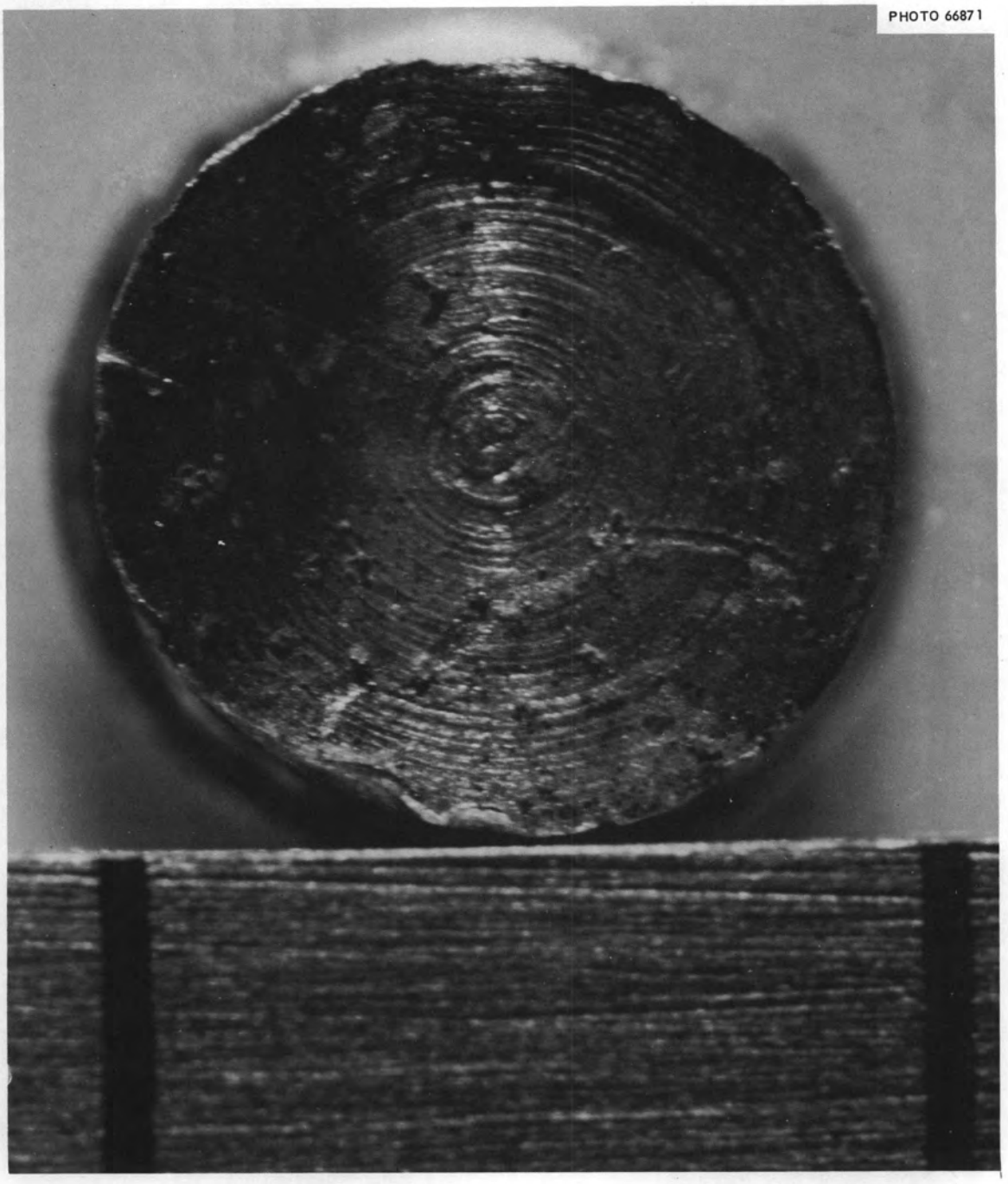

Fig. 5.8. Closeup View of End of Inner Capsule of X-Ray Unit Source Showing Dye Penetration.

Table 5.1. Results of Classification Tests on Sources for X-Ray Unit

Source	Class	Type of test	Leak rate, μg of potassium per ml Sample A[a]	Sample B[b]
S-SS-163A		Initial leak	0.090	0.190
	C	Maximum Temperature Resistance	0.045	0.090
	C	Thermal Shock Resistance	0.030	2.0
S-SS-163B		Initial leak	0.080	0.31
	C	Operating Temperature Resistance	0.080	0.22
	III	Resistance to Crushing	0.088	0.090
S-SS-163C		Initial leak	0.065	0.27
	A	Operating Temperature Resistance	0.022	0.085
	I	Puncture Resistance	0.022	0.24
S-SS-163D		Initial leak	0.080	0.22
	A	Maximum Temperature Resistance	0.022	0.19
	A	Thermal Shock Resistance	0.022	0.060
	I	Resistance to Crushing	0.022	0.060
	I	Resistance to Shear	0.022	0.032
	I	Impact Force Resistance	0.022	17.5
S-SS-164A		Initial leak	0.050	0.22
	B	Maximum Temperature Resistance	0.035	0.083
	B	Thermal Shock Resistance	0.068	0.086
S-SS-164B		Initial leak	0.070	0.25
	B	Operating Temperature Resistance	0.063	0.16
	II	Resistance to Crushing	0.12	0.19
S-SS-164C		Initial leak	0.065	0.23
	A	Operating Temperature Resistance	0.022	0.042
	I	Puncture Resistance	0.022	0.10
S-SS-164D		Initial leak	0.065	0.17
	A	Maximum Temperature Resistance	0.022	0.070
	A	Thermal Shock Resistance	0.022	0.16
	I	Resistance to Crushing	0.022	0.023
	I	Resistance to Shear	0.022	0.082
	I	Impact Force Resistance	0.022	4.5
S-SS-165A		Initial leak	0.050	0.065
	B	Maximum Temperature Resistance	0.033	0.060
	B	Thermal Shock Resistance	0.040	5.5
S-SS-165B		Initial leak	0.042	0.055
	B	Operating Temperature Resistance	0.045	0.075
S-SS-165C		Initial leak	0.042	0.063
	A	Operating Temperature Resistance	0.022	0.025
	I	Puncture Resistance	0.022	0.047
S-SS-165D		Initial leak	0.055	0.065
	A	Maximum Temperature Resistance	0.022	0.24

Table 5.1. continued

Source	Class	Type of test	Leak rate, μg of potassium per ml	
			Sample A[a]	Sample B[b]
S-SS-165D	A	Thermal Shock Resistance	0.022	0.045
	I	Resistance to Crushing	0.022	0.025
	I	Resistance to Shear	0.022	0.030
	I	Impact Force Resistance	0.022	24.5

[a]control samples [b]test samples

5.4. Cobalt-60 Irradiator Sources

Classification tests were conducted on five ^{60}Co gamma irradiator sources (designated S-Co-182A through E). The source material was a 5/8- x 12- x 1/16-in. strip of cobalt doubly encapsulated in stainless steel containers with welded closures (external dimensions: 3/4 x 13 x 5/32 in.).

5.4.1. Initial Leak Test

A vacuum leak test was performed on each source, and no leaks were indicated.

5.4.2. Temperature Tests

Source S-Co-182A was exposed to a temperature of 1700°F in air for 1 hr (Class C Maximum Temperature Resistance test). At the end of the period, a slight discoloration of the steel was noted, but no damage was detected. A vacuum leak test was negative.

This source was then heated to 2550°F* in air for 1 hr (Class D Maximum Temperature Resistance test). The source could not be removed from the furnace at the end of the hour because the capsule had fused to the furnace liner. After the source had cooled, it was removed and inspected (Fig. 5.9). The outer and inner stainless steel capsules were badly oxidized and completely burned off the top of the source.

Fig. 5.9. S-Co-182A After Class D Maximum Temperature Resistance Test (2550°F for 1 hr).

*The Class D Maximum Temperature Resistance test has since been lowered to 2400°F.

The cobalt metal strip was intact but slightly oxidized. (It should be pointed out that this was the expected result for this test since the temperature exceeded that normally specified as the upper limit for stainless steel. For the first series of tests, a source is normally tested to destruction in order to obtain the maximum endurance limit.)

The Class D Thermal Shock Resistance test was performed on S-Co-182C. The source was heated to 1700°F, removed, and immersed in a trichloroethylene-Dry Ice mixture at -76°F. No cracks in the welds or in the capsule were revealed in stereomicroscopic examination of the unit, and no leaks were indicated in the vacuum leak test.

The source was then heated at 1700°F in air for 24 hr (Class D Operating Temperature Resistance test). When examined, the surface was discolored and there was a slight amount of scaling and pitting; however, a vacuum leak test showed no leaks. The source was then placed in an air atmosphere at -76°F for 24 hr; no damage or leaks could be detected.

5.4.3. Structural Tests

Source S-Co-182B was subjected to the Class III Impact Force Resistance test by dropping a 12-lb weight from a height of 5 ft onto an edge of the source. The unit was bent, but the welds remained intact and the source did not leak. The source was then positioned on its edge and loaded with 2000 lb for 1 hr (Class III Resistance to Crushing test). Visible examination showed no additional damage to the source, and the unit continued to be leak free.

For the Class IV Puncture Resistance test, the source was positioned horizontally on a 1/8-in.-dia pin and a 996-g weight was dropped onto it from a height of 5 ft. The capsule was indented 0.03 in. but was not penetrated. This test was repeated using a 1888-g weight (Class V Puncture Resistance test). The capsule was indented 0.05 in. but still was not penetrated. (The indentations can be seen in Fig. 5.10.) This source was then put on its edge in a press and the applied force was increased to ~10,000 lb (Class IV Resistance to Crushing test). At this point, the capsule collapsed, breaking down a weld (Fig. 5.10).

A 20-lb weight was dropped from 6 ft onto the end weld of source S-Co-182D (Class IV Impact Force Resistance test). The source was partially collapsed (Fig. 5.11) but it did not rupture. The unit remained leak free.

Source S-Co-182E was placed in shearing dies and 1000 lb was applied in shear for 1 hr (Class III Resistance to Shear test). The only damage to the source was minor bending (Fig. 5.12). The source was then repositioned in the dies and was found to shear at 8500 lb (Fig. 5.13), a force less than the Class IV Resistance to Shear test requirements.

Fig. 5.10. S-Co-182B After Class IV Resistance to Crushing Test (Indentations from a Class V Puncture Resistance Test Previously Performed on this Source Can be Seen).

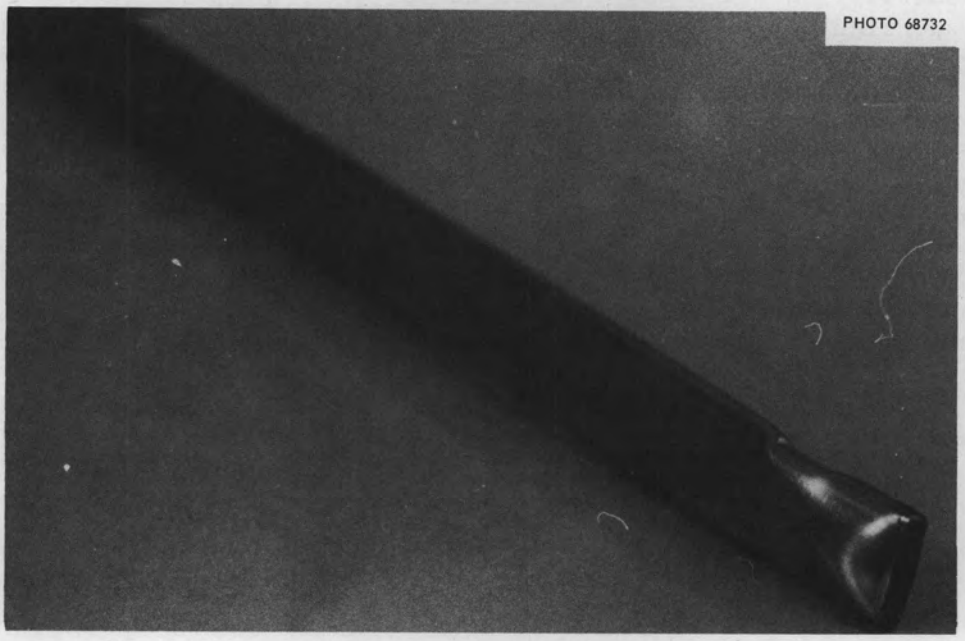

Fig. 5.11. S-Co-182D After Class IV Impact Force Resistance Test.

Fig. 5.12. S-Co-182E After Class III Resistance to Shear Test.

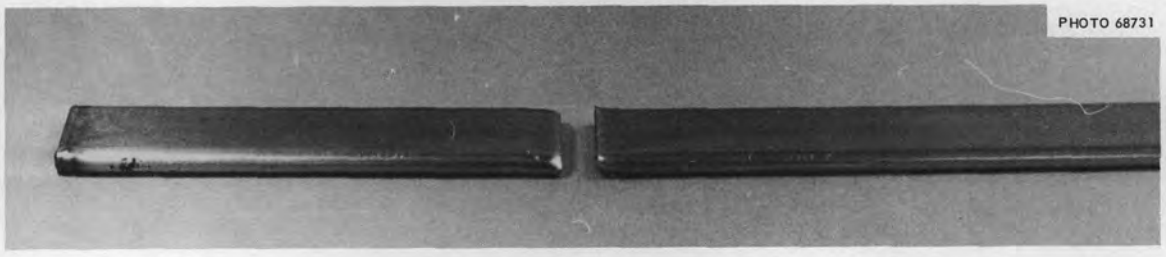

Fig. 5.13. S-Co-182 Sheared to Failure (8500-lb Force).

5.5. Strontium-90 Beta Source (Coil)

A prototype coiled tubular strontium-90 beta source (S-Sr-189) was subjected to the classification tests to determine if it were comparable, from a containment standpoint, with the more conventional disk-type beta sources. The source material was encapsulated in 1/8-in.-dia, 20-mil-wall stainless steel tube 6 ft long which was formed into a coil, 2 in. in dia by 2-1/2 in. in length. The powdered source compound was loaded into the tube by vibratory compaction prior to coiling. The ends of the tubing were sealed by fusion welding.

Before testing, the source was examined with a microscope and found to be free of visual defects; no leaks were found in the vacuum leak test.

5.5.1. Temperature Tests

The source was placed in a furnace and heated at 500°F for 24 hr (Class C Operating Temperature Resistance test). After the unit was cooled to room temperature, the vacuum leak test indicated no leaks. The source was immersed in liquid nitrogen for 24 hr, removed, and allowed to warm to room temperature. No visual damage was evident and the vacuum leak test showed no leaks were present. For the Class C Maximum Temperature Resistance test, the source was heated in a furnace for 1 hr at 1700°F, removed, and cooled to room temperature. The unit was slightly oxidized but showed no visual defects; the vacuum leak test was negative.

This source was then heated to 500°F, transferred to an ice bath, and removed to a -76°F chamber. When returned to room temperature, the source showed no visual defects and the vacuum leak test indicated no leaks.

5.5.2. Structural Tests

The source was subjected to four Class III structural tests. For the Resistance to Crushing test, the source was placed in a press and a 200-lb force was applied for 1 hr. The coil was deformed but not ruptured. The vacuum leak test was negative.

The source was then placed on a 1/8-in.-dia pin and a 225-g weight was dropped from a height of 3 ft, striking the source (Puncture Resistance test). The tubing was indented about 1/16 in. but was not punctured; the vacuum leak test showed no leaks.

Following this test, a 12-lb weight was dropped on the source from a height of 5 ft (Impact Force Resistance test). This caused some deformation of the tubing, but the source did not leak. Another drop was made on one of the end welds. The weld flattened out to 0.07 in. but this compression did not cause a rupture. The vacuum leak test was negative. Figure 5.14 shows the source after this test.

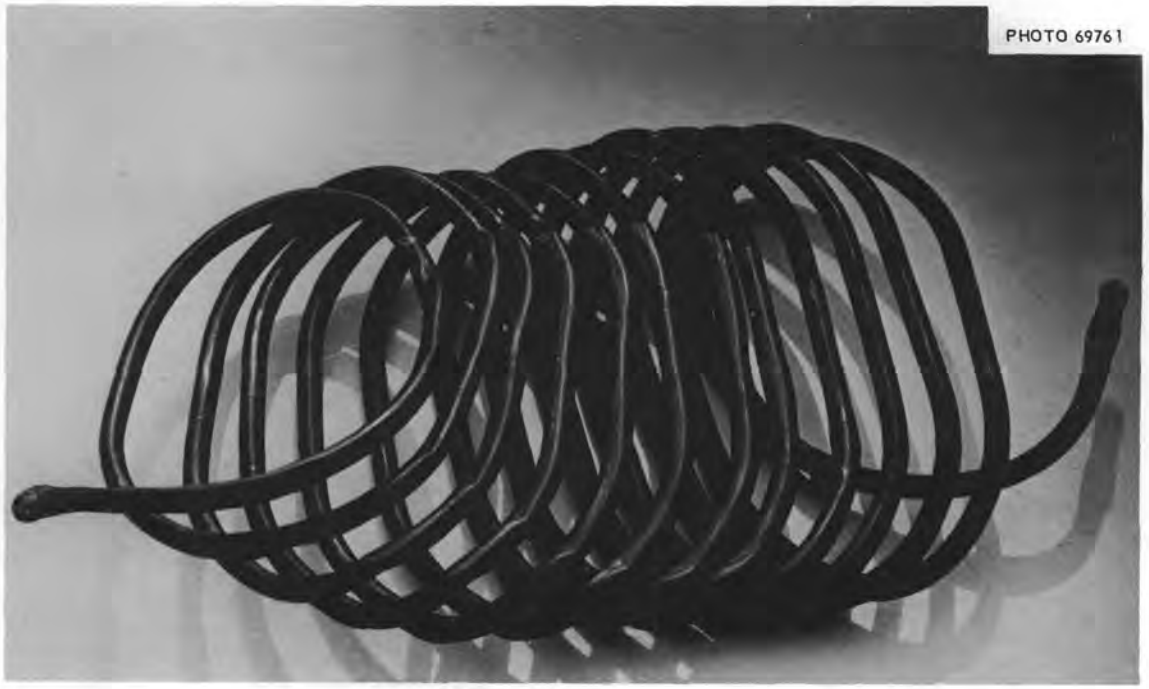

Fig. 5.14. S-Sr-189 After the Class III Impact Force Resistance Test.

In the last test, the source was placed in the shear blocks so that one coil received the entire shear load. The tubing sheared at 450 lb before the Class III requirement of 1000-lb shear force was reached.

5.6. Beryllium Beta Source Capsule

A doubly encapsulated beryllium beta source capsule was designed and fabricated as a possible replacement for a singly encapsulated aluminum source capsule. A 10-mil window was machined at one end of both the inner and the outer capsules. A tapered end cap joint was machined on the opposite ends for sealing by fusion welding. Inactive pellets of mixed rare earth oxides were used to simulate the source material.

Of the five prototype capsules, only three passed the initial vacuum leak tests. Three structural tests were performed: Class III Puncture Resistance, Class II Impact Force Resistance, and Class I Impact Force Resistance. The capsules failed to pass any of these tests. There is difficulty in obtaining consistently good welds with this type of capsule, and the units have low impact strength. Figure 5.15 shows the source before assembly.

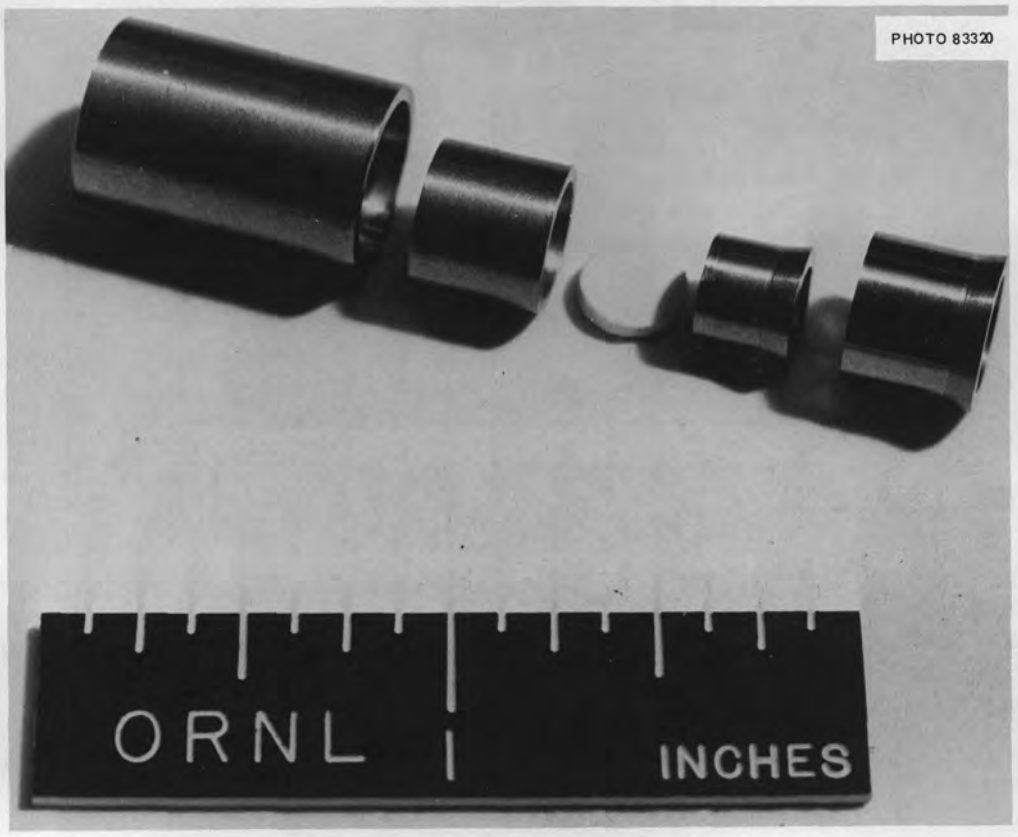

Fig. 5.15. Beryllium Beta Source Capsule Prior to Assembly.

5.7. Stainless Steel Beta Source with Beryllium Windows

A doubly encapsulated stainless steel beta source having 10-mil beryllium windows in both the inner and outer capsules was designed and fabricated for testing. The windows were brazed to the stainless steel capsules using a 960°C braze material. The capsules were sealed by fusion welding in

copper heat sinks without detectable damage to the bronze joint between the stainless steel capsule and the beryllium window. Figure 5.16 shows the source before assembly.

Fig. 5.16. Stainless Steel Beta Source With Beryllium Windows Prior to Assembly.

With inactive rare earth pellets as source material, 43 windows were tested with a helium mass-spectrometer leak detector, and only one small leak (10^{-8} cm^3/sec) was found. The source passed the Class III Puncture Resistance test but failed the Class IV test; it passed the Class II Resistance to Crushing test but failed the Class III test.

ACKNOWLEDGEMENTS

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APPENDIX A

Table 1. ORNL Source Capsule Classification System
Temperature Characteristics

Class	Maximum temperature resistance, °F	Operating temperature, °F	Thermal shock, °F	Temperature-humidity cycling
A	400 for 1 hr	32 to 212	212 to 32 then to -70	200°F – 95% RH to 35°F – 5% RH 8-hr cycle time for 48-hr period
B	750 for 1 hr	-40 to 212	212 to 0 then to -70	Same as A
C	1700 for 1 hr	-320 to 500	500 to 32 then to -70	No requirement
D	2400 for 1 hr	-70 to 1700	1700 to -70	No requirement
E	4500 for 30 min 2400 for 1 hr	32 to 2400	2400 to -320	No requirement

Table 2. ORNL Source Capsule Classification System
Structural Characteristics

Class	External pressure, psig	Puncture resistance, ft/sec onto 1/8-in.-dia pin	Crushing force, lb for 1 hr	Shear strength, lb for 1 hr	Impact force		Vibration
					<2 lb, ft-lb	>2 lb, ft free fall	
I	30	14	200 for 15 min	40 for 30 min	20	10	10 cps at 10 g's (longest axis) for 12 hr
II	100	23	200	100	30	15	Same as Class I
III	1,000	31	2,000	1,000	60	30	No requirement
IV	3,000	44	20,000	10,000	120	60	No requirement
V	10,000	62	50,000	25,000	240	120	4 hr at each resonance*

*5 to 500 cps and 0.001- to 0.1-in. double amplitude applied along each of three perpendicular axes; when no resonant frequencies are found, vibrate for 12 hr at 0.018-in. double amplitude and 150 cps on each axis.

APPENDIX B

SOURCE CAPSULE CLASSIFICATION TEST PROCEDURES

1. Source Capsule

1.1. Definition

For the purpose of classification, a source capsule is defined as the totally assembled, sealed enclosure which provides the containment of the radioactive material. It includes both single enclosure or multiple enclosures but does not include housings, shields, or other devices external to the sealed containment enclosure.

1.2. Classification

The classification system is composed of two sections: Temperature Classes A through E and Structural Classes I through V. Each source capsule design under consideration will be classified in both of these categories to give a composite classification (such as C-I, A-III) which describes both the temperature and structural integrity of the capsule.

The initial classification of a source capsule design shall be made using "dummy" source capsules in which a nearly equal volume of the nonradioactive anhydrous source compound is substituted for the radioactive material. A chemical analog shall be used in cases where a nonradioactive compound is excessively expensive or does not exist. In certain cases a quantity of lithium chloride will be blended with the nonradioactive material to facilitate leak testing, as stated in Section 2.4 of this appendix. The dummy source capsules shall be made of the same materials of construction and manufactured in the same manner as the radioactive source capsules.

For the initial classification of a source capsule, a study of the source capsule design will usually reveal the most susceptible areas of failure due to structural and temperature limitations. Tests may be performed in these areas first in order to establish the limits in the most likely areas of failure.

For reasons of economy, the source capsule classification tests may be performed in any desired sequence. Source capsules may be used for more than one test if it is not likely that they are damaged to an extent that would cause failure in additional testing; however, if a capsule is used for more than one test and it fails the additional test, the test failure shall be verified by retesting with a new source capsule.

2. Source Capsule Leak Test Procedures

2.1. Leak Test Criterion

Unless specifically stated as a part of a test procedure, the only criterion to be used in indicating failure of a source capsule to pass a reclassification test is whether or not it passes the required leak test. Source

capsules having a free volume of 0.25 cm^3 or more shall be tested using the vacuum leak test procedure described in Section 2.2. Source capsules with <0.25-cm^3 free volume shall be tested using the lithium chloride leach test procedure described in Section 2.4.

The free volume of a source capsule shall include all void space within the outer sealed enclosures, including any void space in a porous substitute source compound. In a doubly encapsulated source it includes the void space in the inner capsule plus the void space between the inner and outer capsule.

2.2. Vacuum Leak Test Procedure[1]

2.2.1. Evacuate the leak test chamber for 1 min or longer to lower the dissolved air content of the leak test fluid.

2.2.2. 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.

2.2.3. Evacuate the leak test chamber slowly to a minimum of 22 in. Hg, observing for the positive indication of leaks through the evolution of bubbles from the source capsule surface; do not exceed 25 in. Hg. If no leaks are observed over a period of 5 min, the source capsule is considered to be leak free for the purpose of this test.

2.2.4. Clean the capsule in water and air dry before it is used in another test.

2.3. Vacuum Leak Test Equipment Specifications

The vacuum leak test chamber shall be made of colorless, distortion-free, transparent material with sufficient strength to withstand a vacuum of one atmosphere. It may be of any size and shape provided it is large enough to completely submerge the source capsule being tested under a minimum of 2 in. of the leak test fluid. The leak test fluid shall be reagent-grade ethylene glycol or reagent-grade isopropyl alcohol.

2.4. Lithium Chloride Leach Test Procedure

When source capsules are to be leak tested by this procedure, 20% of the volume of the source compound or chemical analog being used as a substitute for the radioactive material shall be replaced with reagent-grade, anhydrous, lithium chloride. The mixture shall be thoroughly blended before use in fabricating the source. In any case where it is impractical to blend the lithium chloride with the substitute source compound, a volume of lithium chloride not less than one-half the calculated free volume shall be placed inside the capsule adjacent to the substitute source compound.

2.4.1. Place the source capsule in a vacuum flask. Add a known volume of distilled water of known lithium content to completely cover the source capsule (not less than 15 ml).

2.4.2. Evacuate the flask to 22-25 in. Hg vacuum. Maintain at this vacuum for 3 min. Vent the flask to atmospheric pressure and maintain at this pressure for 3 min. Repeat this vacuum-venting procedure four times.

2.4.3. Remove the source capsule slowly, allowing the water to drain back into the vacuum flask.

2.4.4. Reduce the volume of the leach water to 10 ml by boiling. If the volume drops below 10 ml, correct it to 10 ml by dilution with distilled water of known lithium content.

2.4.5. Analyze the water from step 2.4.4 for lithium content using an analytical technique capable of detecting 0.001 μg of lithium per ml.[9] If the sample contains no more lithium than the initial water, the source capsule passes this leak test.

2.5. Lithium Chloride Leach Test Materials Specification

The materials used in this test shall be selected so that blank analytical determinations yield an essentially lithium-free water sample (<0.001 μg/ml). The nonradioactive compound and any other material in the source shall be selected so that any interference with the lithium analysis can be eliminated or corrected by analytical techniques. [The limit of detection can be more sensitive (<0.001 μg lithium per ml) but not less sensitive (>0.001 μg lithium per ml)].

3. Maximum Temperature Resistance

Prior to this test the source capsule specified in Section 1 shall have passed the leak test specified in Section 2.

3.1. Test Procedure for Classes A, B, C, and D

3.1.1. The source capsule shall be placed in a furnace which has been preheated to the required temperature. The source capsule shall be held at the temperature and for the time interval required in the classification system. This test shall be conducted in an air atmosphere.

3.1.2. The source capsule shall be removed from the furnace and allowed to cool in air to room temperature.

3.1.3. The source capsule shall be visually examined for an obvious failure and then subjected to the leak test as described in Section 2.

3.2. Test Procedure for Class E

3.2.1. The source capsule shall be placed in the furnace at room temperature. In the absence of oxygen, the temperature shall be raised to 4500°F and held at this temperature for 30 min and then cooled to room temperature.

3.2.2. The source capsule shall then be placed in a furnace having an air atmosphere and tested using the Class D Maximum Temperature Resistance test as stated in steps 3.1.1, 3.1.2, and 3.1.3.

3.3. Furnace Specifications for Classes A, B, C, and D

The furnace may be of any type capable of operation at the test temperature in an air atmosphere. The furnace must be large enough so that the entire source capsule will be maintained at the required temperature during the test.

3.4. Furnace Specifications for Class E

The specifications for the furnace used in Class E are the same as those for Classes A, B, C, and D except that the furnace for the 4500°F test shall be either a vacuum or an inert gas furnace.

4. Operating Temperature Resistance

Prior to this test the source capsule specified in Section 1 shall have passed the leak test described in Section 2.

4.1. Test Procedure

4.1.1. The source capsule shall be placed in a cooling chamber which has been precooled to the lower operating temperature required in the source capsule classification system. This test shall be conducted in any atmosphere which does not react chemically with the source capsule.

4.1.2. This temperature will be maintained for 24 hr. At the end of this time, the source capsule shall be removed from the cooling chamber and allowed to return to room temperature.

4.1.3. The source capsule shall then be visually inspected for failure and subjected to the leak test described in Section 2.

4.1.4. The source capsule shall be weighed to the nearest 0.0001 g and placed in a furnace which has been preheated to the upper limit of the operating temperature required in the source capsule classification system. This temperature shall be maintained for 24 hr. The test shall be conducted in an air atmosphere.

4.1.5. The source capsule shall then be removed from the furnace and allowed to cool to room temperature. Then the source capsule shall be weighed to the nearest 0.0001 g.

4.1.6. The source capsule shall be visually inspected for failure and subjected to the leak test described in Section 2.

4.1.7. If the source capsule either gains or loses weight equivalent to oxidation of 1% or more of the least outer wall thickness, then the same source capsule shall be retested under Section 4 (steps 4.1.4 through 4.1.7). Step 4.1.7 may be repeated not more than three times. If the source capsule does not gain or lose weight equivalent to oxidation of 1% or more of the outer wall thickness in any one of the three allowed tests, then the source capsule passes the required upper limit of the operating temperature test, providing it also passes the leak test in step 4.1.6.

4.2. Furnace and Cooling Chamber Specifications

The furnace shall be of any type, provided the required temperature may be maintained in an air atmosphere. The geometry of the furnace and cooling chamber shall be such that the entire source capsule will be at the required temperature during the test.

5. Thermal Shock Resistance

Prior to this test the source capsule specified in Section 1 shall have passed the leak test described in Section 2.

5.1. Test Procedure

5.1.1. The source capsule shall be placed in a furnace which has been preheated to the required upper temperature limit in the source capsule classification system and held there until the source capsule is at the required temperature. The source capsule shall then be plunged within 1 sec into an atmosphere which will eventually reduce the source capsule temperature to the required lower limit of the test.

5.1.2. For Classes A through C the source capsule, upon reaching the required lower temperature limit, will be placed in an atmosphere that will reduce the source capsule temperature to -70°F within 15 min.

5.1.3. Upon reaching -70°F for Classes A through D, or -320°F for Class E, the source capsule shall be removed from the cooling atmosphere and allowed to return to room temperature.

5.1.4. The source capsule shall then be visually inspected for failure and subjected to the leak test described in Section 2.

5.2. Furnace and Cooling Chamber Specifications

Any furnace or cooling chamber having any atmosphere and utilizing any heated or cooled fluid may be used as long as the entire source capsule is heated or cooled to the required temperature.

6. Temperature-Humidity Cycling Resistance

Prior to this test the source capsule specified in Section 1 shall have passed the leak test described in Section 2.

6.1. Test Procedure for Classes A and B

6.1.1. The source capsule shall be placed inside the temperature-humidity chamber and subjected to the following 8-hr cycle for a period of 48 hr:

> 200°F and 95% relative humidity to 30°F and 5% relative humidity and then back to 200°F and 95% relative humidity.

6.1.2. The source capsule shall then be visually inspected for failure and subjected to the leak test described in Section 2.

6.2. Test Procedure for Classes C, D, and E

No test is required for these classes.

6.3. Temperature-Humidity Chamber Specifications

Any temperature-humidity chamber capable of reproducing the above repeated cycle is acceptable provided the volume is greater than eight times the total volume of all the capsules tested at one time. If more than one capsule is tested at one time, they shall be placed in the chamber so that they are separated by at least two capsule diameters.

7. External Pressure Resistance

Prior to this test the source capsule specified in Section 1 shall have passed the leak test described in Section 2.

7.1. Test Procedure

7.1.1. In all cases where water is used as the pressurizing fluid, the source capsule shall be weighed to the nearest 0.0001 g before pressurizing.

7.1.2. The source capsule shall be placed inside the test apparatus, subjected to the external pressure required by the classification system for 15 min, and then removed.

7.1.3. In all cases where water is used as the pressurizing fluid, the source capsule shall be allowed to completely dry at room temperature and then be weighed to the nearest 0.0001 g. If the source capsule gains more than 0.0005 g, it shall be regarded as failing this test. If the weight gain is 0.0005 g or less, the test shall be continued as in step 7.1.4.

7.1.4. The source capsule shall be visually inspected for failure and then be subjected to the leak test described in Section 2.

7.2. Test Apparatus Specifications

The test apparatus shall consist of pressure vessel and any source of pressure capable of operation at the required conditions. The pressurizing fluid shall be water, air, or nitrogen.

8. Puncture Resistance

Prior to this test the source capsule specified in Section 1 shall have passed the leak test described in Section 2.

8.1. Test Procedure

8.1.1. The source capsule shall be placed on the puncture pin and so oriented that the surface most susceptible to failure is in contact with the pin, with the major axis of the source either perpendicular to or parallel to the applied impact force.

8.1.2. A weight equal to the weight of the source shall be dropped in free fall on the source from a height sufficient to give the required impact velocity; or a weight not to exceed 12 times the weight of the source capsule shall be dropped from a height determined by multiplying the ratio of the mass of the source to the mass of the weight by the height that would be required by a weight equal to the weight of the source capsule. The weight shall be dropped so that its center of gravity is nearly in line with the puncture pin.

8.1.3. The source capsule shall then be visually inspected for failure and subjected to the leak test described in Section 2.

8.2. Apparatus Specifications

The apparatus shall consist of equipment to assure the proper alignment of the weight, source capsule, and puncture pin. The puncture pin shall be mounted vertically in steel on a firm base and shall be 1/4 in. in height. It shall be a 1/8-in.-dia pin having a rounded end (1/16-in. radius) and a Rockwell hardness of at least C-45.

9. Resistance to Crushing

Prior to this test the source capsule specified in Section 1 shall have passed the leak test described in Section 2.

9.1. Test Procedure

9.1.1. The source capsule shall be placed in a press or vice with piston or jaws and the required force applied for the required time. The source capsule shall be oriented in a position most susceptible to failure with the major axis of the source either perpendicular to or parallel to the applied force.

9.1.2. At the end of the required time the source shall be visually inspected and then subjected to the leak test described in Section 2.

9.2. Equipment Specification

The equipment may be any press or vise having flat pistons or jaws, the faces of which are parallel to each other. The faces shall be at least 2 in. in dia.

10. Resistance to Shear

Prior to this test the source capsule specified in Section 1 shall have passed the leak test described in Section 2.

10.1. Test Procedure

10.1.1. The source capsule shall be placed in the shearing device and the required force applied for the required time. The shearing edges shall be placed in the area of most susceptible failure with the major axis of the source either perpendicular to or parallel to the applied force.

10.1.2. The source capsule shall then be removed, visually inspected for failure, and subjected to the leak test described in Section 2.

10.2. Test Equipment Specifications

The equipment used for this test will consist of a device with 90° edges hardened at a Rockwell hardness of C-65. One edge will be mounted solidly and will be equipped to hold the source capsule in a fixed position so that it cannot move during testing. The other edge shall have the capability of moving in a plane parallel to and collinear with the fixed edge when the required shear force is applied to the capsule. Both ends of the capsule are to be solidly supported to minimize bending of the capsule during the test. The shearing edges may be circular to more nearly conform to the capsule geometry.

11. Impact Force Resistance

Prior to this test the source capsule specified in Section 1 shall have passed the leak test described in Section 2.

11.1. Test Procedure No. 1 (Capsules <2 lb)

11.1.1. For source capsules weighing <2 lb, the source capsule will be placed near the center of the test pad with the most susceptible surface up and the major axis of the source either perpendicular to or parallel to the applied force.

11.1.2. The cylindrical weight shall be dropped so that the flat end strikes the most vulnerable surface of the source capsule from a height such that the required impact is obtained.

11.1.3. The capsule shall then be visually inspected for failure and subjected to the leak test described in Section 2.

11.2. Apparatus for Test Procedure No. 1

The apparatus shall consist of the necessary equipment to assure the proper vertical alignment of the cylindrical weight and the source capsule. The cylindrical weight shall have a minimum diameter of 2 in. and shall be hardened to at least 45 on the Rockwell C scale. The ends of the weight shall have 1/16-in.-radius edges. The test pad shall be a flat surface of steel hardened to 45 on the Rockwell C scale. It shall be mounted in a horizontal plane and reinforced by concrete or other materials, if necessary, to give an essentially unyielding surface.

11.3. Test Procedure No. 2 (Capsules >2 lb)

11.3.1. For source capsules weighing >2 lb, the capsule shall be dropped in free fall from the required height in such a way that its most susceptible surface strikes the test pad.

11.3.2. The source capsule shall then be visually inspected for failure and subjected to the leak test described in Section 2.

11.4. Impact Apparatus for Test Procedure No. 2

The apparatus shall be capable of holding the source capsule at the required height and releasing it in such a manner as to allow it to fall freely without rotation until impact. The test pad shall have the same requirements as described in Section 11.2.

12. Vibration Resistance

Prior to this test the source capsule specified in Section 1 shall have passed the leak test described in Section 2.

12.1. Test Procedure

12.1.1. The source capsule shall be attached to the vibrating device and tested at the conditions required.

12.1.2. The source capsule shall then be visually inspected for failure and subjected to the leak test described in Section 2.

12.2. Equipment Specifications

The equipment shall be capable of test operations over the range of variables listed in the source capsule classification guide.

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