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Radon Leakage from Navy
Radium Capsules

NAVAL RESEARCH LABORATORY

Washington 20, D. C.

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NAVY DEPARTMENT

Report on

RADON LEAKAGE FROM NAVY RADIUM CAPSULES

NAVAL RESEARCH LABORATORY
ANACOSTIA STATION
WASHINGTON, D. C.

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Abstract

A series of field and laboratory tests were carried out to determine the extent of radon leakage in radium capsules owned and used by the Navy for gamma radiographic inspection. The majority of the capsules tested showed leakage to a greater or less extent. Tests were carried out to determine best means of sealing leaking capsules in steel cartridges. These showed that this may best be done by solder sealing the steel cartridges. The internal cavity of the cartridge must be kept to a minimum to avoid loss of radiographic definition.

INTRODUCTION

A. Authorization

1. The tests described in this report were authorized by BuShips ltr JJ 46-11 (773c) of September 5, 1942, and JJ46-11 (773c) of October 31, 1942.

B. Statement of the Problem

2. The purposes of the tests conducted were:

(a) to determine to what extent radon leakage detected in some instances in radium units while under repair at the Naval Research Laboratory exists among the number of radium capsules in use at Naval Stations and (b) to determine practical measures for avoiding danger topersonnel as a result of radon leakage occurring in such cases. These measures include possible use of leaking capsules in sealed containers to avoid loss of use of necessary radium units.

C. Known Facts Bearing On The Problem

3. The Navy radium capsules are purchased according to bid specifications first drawn up in March 1931. These specified the use of a silver container made of silver alloy containing 10 - 20% of copper and having a minimum wall thickness at any point of at least 1/2 mm., all joints to be silver soldered with an alloy of substantially the same composition as the wall material. It was believed at the time of this adoption that the material would prove satisfactory and facilitate the manufacture of a radium capsule which would be leak tight indefinitely. Other materials have been used for the construction of radium capsules; among them, platimum, which is a more substantial material but suffers from the drawback that sealing operations are more difficult to perform.

4. To improve the radium capsule itself it might be suggested that other materials be used for construction of the capsule. While no doubt, time and effort spent on a project of this type would yield a material that would be superior to that now used, it must be said that the silver alloy possesses certain advantages that are hard to discount such as its malleability, its low melting point allowing sealing at moderate temperatures and fair degree of corrosion resistance. Alloys of silver with copper of the composition used are substantially 2 phase alloys. Even with very small amounts of copper it is doubtful whether a homogeneous alloy would be obtained. Furthermore a certain amount of copper can be retained in solid solution by cooling rapidly from the fusion temperature which may tend to precipitate slowly and set up strains within the metal. These can be eliminated to a large extent by suitable heat treatment. The present capsule may be improved by making the wall thickness somewhat larger thereby making the escape of gas by diffusion and by traversing microcracks more difficult and also by allowing somewhat larger areas of contact in the solder joints which are very likely the principal points of leakage. Improvement is also

possible by taking care that the solder is not of a composition detrimental to the capsule material and that the capsule is made strain free as possible by a careful anneal followed by a slow cooling. The specification that the solder be of substantially the same composition as the capsule material if interpreted as meaning the same composition as the capsule material would make difficult the sealing operation as the solder would have so high a fusion point that the capsule material would be fused in its soldering operation. In commercial silver solders, the melting point is brought down by addition of other elements such as zinc. Whether or not the zinc addition makes the soldered joint less stable or subject to cracking is hard to say. Zinc will dissolve in solid solution in silver up to around 27% at room temperature and is then more soluble in the silver than the copper alloy addition. The zinc dissolved in the solder alloy may alter the chemical e.m.f. of the metal to an extent promoting the corrosion of the metal at the joint or between given boundaries on the metal. That a silver alloy capsule can be made that is leak-tight is known and some of the Navy capsules have been in use for many years without yet showing signs of appreciable leakage.

5. The radium capsule after sealing by its manufactures should remain relatively imperious to the radon gas in equilibrium with the radium sulfate contained within, the ordinary rate of diffusion of gas atoms through silver at room temperature being very small. The escape of appreciable amounts of radon from the radium capsule occur only when cracks have been formed either in the silver alloy wall or in the silver solder joints as a result of internal strain set-up within the metal or even by damage due to violent mechanical handling of the capsule.

6. Plate 1 shows a photograph taken of a section through a silver alloy capsule and also of a complete capsule. The construction is such that the wall thickness of the capsule is substantially uniform but it must be noted by the evident tarnishing at the joints as seen in the external view that a condition of inhomogeneity exists at these points which may be condusive to promoting cracking and leakage through these joints.

7. Under these conditions an escape of radon and its decomposition products can take place and the receptacles of the radium carrier safes are logical places to expect such contamination. Dirt from these places may get on the hands of the radium operator and even lead to radium poisoning unless precautions are taken. Ordinarily the necessity of keeping the operator's person as far as possible from the radium source implies handling the source from a distance of a foot or more at the very least in which operation the operator need not touch the radium carrier safe at all except to open the cover and this may be done with a wire, rod or cord. Occasionally when the radium source has been removed it is necessary to clean out dirt that finds its way into the carrier box in normal use in the foundry and shop. Under these conditions there is possibly considerable danger to one's person if the radium cartridge in that safe is leaking to some extent.

8. The escape of the radon gas from the radium capsule may or may not present a hazard to persons handling this radium depending on the conditions. Tests to be described herein have shown that badly leaking radium capsules enclosed in loosely closed cartridges (ordinary mechanical screw joint) will allow enough radon gas to escape into a small volume surrounding the cartridge to be equivalent to a radium source of considerable strength. Furthermore this accumulated radon on decomposing leaves solid decomposition products whose radioactivity may be very high depending on the concentration of the radon producing it. In case a cartridge is used in an unconfined space and where there may be a sufficient movement of air past the radium source as will be the case in gamma radiography performed in the open or in large shops, the radon escaping from the cartridge may have opportunity to diffuse away rapidly into the air and present little or no personal hazard. When the radium source is not in use it is housed in its carrier safe and the volume of air surrounding the cartridge is small.

D. Experimental And Test Methods

9. Before 1942 no systematic attempt was made to check the Navy capsules in service for radon leakage. The capsules were inspected in the field or in the laboratory only at such times as was necessary to make repairs to the external cartridge such as repairs to broken eyelets, etc. In such cases the capsules were removed from these cartridges. If these showed signs of excessive corrosion they were taken to the Bureau of Standards for checking. In this way a case of leakage came to attention when a 510 mg Radium Unit(No. 6)was found leaking in August 1940. This capsule was completely overhauled by resealing the radium salt in a new capsule but the operation entailed the loss of about 50 mg which was replaced in the form of a separate radium capsule. For this reason no subsequent attempts were made to have the leaking radium capsules repaired in this way. Thereafter repairs were made by the manufacturer using tin solder coating to seal the capsule. Sufficient data has not accumulated to learn how satisfactory and permanent this method of repair is.

10. As a result of radon leakage it is to be expected that an accumulation of radioactive products will be formed in the surroundings about the source such as the cotton packing and the walls of the duralumin or steel radium cartridge. Radioactivity of these should be a good indication of the extent of radon leakage from the radium capsule itself. As a simple practical test for determining radon leakage from the capsules taken from the cartridges the cotton packings were placed in a Kelvin chamber electrometer. Plate 2 shows this instrument and equipment for making the test. A test made in April 1942 showed that it was easy with the given instrument to show radioactivity equivalent to that produced by a mg. of thoria or about 10^{-9} g of Ra. The cotton packings from radium Unit No. 32 showed a slight but definite activity of this order. During the following month (May 27) a test was made on the packings from Radium Unit No. 22. This time a much larger leakage was noted (Natural rate 0.2 deg. min. with packing 11° min). Confirm-

atory tests were made at the Bureau of Standards on both packing and capsule itself. This unit was repaired by tin solder coating by the Radium Chemical Company and returned to service. Following this a similar unit No. 21 (100 mg) was also found leaking considerably and repairs were required.

11. Following discoveries of radon leakage of this type in radium units arriving at the laboratory for repair or storage, it was recommended[1] to the Bureau of Ships that a survey be made to determine to what extent the Navy radium capsules were leaking by examining a number of representative capsules in use in this region. A field inspection trip was authorized for this purpose[2]. Eleven radium capsules from nine radium units were tested. The units varied in strength from 50 to 500 mg. The results of these tests have been reported to the Bureau (Travel Report NRL N8-12 Radium, 433 blv Sept. 26, 1942). The method of examining each unit was that described above - testing of the cotton packing from each radium cartridge by means of an electroscope instrument (Kelvin electrometer) or by means of a thin walled Geiger Muller counter operated from a small portable battery supply. Both methods were found adequate. In general the results of these field tests given in Table I showed that all but one of the capsules tested were leaking radon. In some cases this leakage was moderate. The background rate of the electroscope being 5-18^{o} min. such as noted in the case of Unit No. 22. In most cases the decay of the electroscope was so rapid that a very strong radon leakage was indicated. This was the case for radium units 18 + 19, 36 + 37, 23 and 20 and it has been recommended that repairs be made to these capsules. Since the radiographic radium is needed to carry out inspections its loss from service is undesirable in many cases. For this reason it was suggested that tests be made to see if the leaking radium capsules can be enclosed in the steel radium cartridges in such a way that no escape of radon from these capsules can take place.

(1) NRL ltr N8-12 Ra(433) 16 Sept. 1942
(2) NRL Travel Order P16-4 (9) Kaiser H. F. Sept. 1942

TABLE I

RESULTS OF ELECTROMETER MEASUREMENTS OF PACKINGS

Units No.	Mg. Ra.	Natural Rate of Electrometer	Rate With Sample	Remarks
18 + 19	500	Deg/Min 0.70°	40 - 160°/sec.	
39	50	1.75°	50/min.	
6	410	1.16	1.16°	Good Capsule
36 + 37	500	1.16	300°/sec.	Very powerful residue
23	500	1.75	Too rapid to measure	80°/sec.with res.just outside of electro-scope
9	450	4.0	17.5 45°min.	
50	100	4.75	69.2°/min.	
50	100	10.2	Too rapid	80°/sec.with res.just outside of electro-scope
46	250	8.8	18.6°/min.	

12. Units No. 20 and 36 + 37 were made available by the Bureau for these tests. A special Geiger-Counter fitted with a radium cartridge holder and mercury pump was designed for making these tests.

13. The counter-apparatus is shown in Plate 3. In this drawing is seen the receptical W with stopcock arrangements for holding a steel radium cartridge C, the Geiger-counter tube T connected at the top to both the cartridge well W and a pump cylinder P by means of the central stopcock S_2. In use the radium cartridge is placed in the well C and the cone stopper with stopcock S is put in place. The central cylinder P is filled with mercury from a leveling flask connected to the lower end with rubber connecting hose. After filling, the central stopcock S_2 is turned so that the mercury column is connected directly to the cartridge well W and also so that the counter chamber is not. The mercury level is then lowered leaving the cartridge well under vacuum to aid the escape of radon from the cartridge. After being under vacuum a desired test time the cartridge well is flushed by repeatedly letting in air through the stopcock S_1 on the well until a sufficient volume of gas exists in the gas cylinder P to fill the gas specimen chamber V of the Geiger counter. The central stopcock S_2 is then turned to connect the gas cylinder P to the chamber V on the Geiger-counter and the stopcock S_3 on this chamber is operated to allow passage of air. The mercury level is raised to force the gas into the counter chamber, the air in the chamber and excess being passed off through the counter chamber's stopcock S_3 through a connecting tubing to a gas reservoir designed to hold several volumes of the pump chamber. With this reservoir it is possible to remove the radon bearing air from the apparatus by repeated flushings and finally, by disconnecting the reservoir, to remove it to some place where the gas in the reservoir may be safely released and the reservoir emptied out.

14. The complete apparatus consisting of Geiger-counter and electrical equipment for use with it is shown in Plate 4. Here is shown a cathode ray oscilloscope for indicating the Geiger counter pulses, the cabinet housing the voltage generating circuit for the counter and the meter circuit for indicating the counting rate, the counter apparatus with cartridge well shielded in a lead jacket, and finally the storage reservoir. This equipment was completed by December 10, 1942.

15. On passing the radon-bearing air sample from the cartridge well W into the counter chamber V there will be observed an initial gain in the counting rate due to the admission of the sample, a subsequent gain due to the deposition of solid radioactive decomposition products on the thin window of the counter tube followed by a decrease in counting rate due to decay in activity of the radon and its decomposition products. After flushing the counter chamber with air solid decomposition products remain on the counter window and wall of chamber V and maintain the counting rate. To bring the counter back to its original background rate it is necessary to remove these products by washing the window and chamber with an acid solution or by waiting until the decomposition products have decayed to negligible activity.

16. To gain some idea of the sensitivity of the apparatus a test was made on a small radium source simulating a leaking radium capsule. An open capsule was made containing about 1 g radium luminous compound having a radium content equivalent of about 10 micrograms. The 1/8 inch orifice in this capsule was closed with a cotton plug. This capsule was placed in the cartridge well of the counter apparatus and allowed to remain overnight at atmospheric pressure. Then the flushing and pumping operations described above were carried out. The meter circuit was set to its longest time constant and counting rate current read directly without use of the auxiliary bucking circuit. The introduction of the gas from the test samples into the counter chamber caused a five-fold increase in counting rate in two hours. This rate was maintained over several hours of observation. The ability of the apparatus to detect radon accumulation of this order thus assured its ability to detect radon leakage from large and powerful sources.

17. The first test on an actual cartridge was made after Radium Unit No. 20 was received on Dec. 21, 1942. It was not necessary to make any test for leakage of the capsule with the counter apparatus since the packings from this cartridge showed strong activity due to leakage. This capsule was placed within a half inch steel cartridge fitted with a 0.006 inch lead gasket compressed as far as possible by tightening the cap screw. See Plate 5 (a). The whole cartridge was placed in the counter apparatus and the cartridge allowed to remain overnight at atmospheric pressure. Tests made on flushings from the cartridge well showed no definite increase in counting over two hours of observation. A more prolonged test under vacuum was carried out. The cartridge was kept under vacuum over the week but no definite increase in counting rate could be established.

18. After its arrival, the cartridge containing capsules for Units No. 36 and 37 was placed in the apparatus without opening the steel cartridge in order to get an idea of the leakage which may occur from a steel cartridge employing no gasket. In this case the cartridge had been closed with liquid glyptal on the joint about three months previously. The cartridge was placed under vacuum in the apparatus overnight. On beginning tests the next morning the counting rate after removal of the cartridge from the apparatus was very large indicating a considerable accumulation of radon in the apparatus.

19. After cleaning out the counter apparatus with a nitric acid solution another test was made on a cartridge containing the leaking capsule of Unit No. 36 which was fitted with a copper gasket. The cartridge was stored overnight under vacuum. A small gain was noted in the output of the counter meter on introducing the flushings from the well into the counter but no gain was observed for some time thereafter. The small gain cannot be taken as certain indication of leakage. A repeat test indicated the possibility of slight leakage.

20. The results of the above and further tests are summarized in Table II in which it may be noted that a variety of gaskets were tried using copper and lead as gasket materials. Even though due allowance for sensitivity due to drift in the Geiger counter meter circuit be made it may be noted that definite leakage was observed with various types of mechanical seals. These seals made with copper and lead gaskets are possibly fairly tight and reduce leakage to a small amount but it may be noted that these may become loose or may not be properly made. In test No. 13 a seal was tried in which a wire solder gasket was trapped in a lodged recess machined on the inside of the cartridge body. This seal seemed tight in first test and was thought to be the best tried but further tests showed that this also gave slight indication of leakage. Finally sealing the cartridge by means of tin solder was considered. A preliminary test on the efficiency of a solder joint on the material of the cartridge body was made by making a soldering test on a small Hypernik alloy specimen for simulating the lower end of the radium cartridge. This was tinned with zinc chloride flux and soldered with a special lead tin alloy solder. Plate 7 shows the cross-section of this alloy specimen and also a photo-micrograph of a section of the solder joint which is definitely not perfect throughout its length and indicates that care must be taken in making such joints.

21. The results however indicated that with care a gas tight joint could perhaps be obtained in the radium cartridge and further tests were made in tinning and soldering the radium cartridges. Apparatus was constructed for holding the radium cartridge in a small furnace in which a small steel cup holding solder and flux could also be placed for tinning the parts of the cartridge. With this No. 36 capsule was sealed into a steel cartridge using asbestos thread to fill space in the cartridge not occupied by the capsule. The cartridge body was heated to over 600° F as measured by a Chromel-alumel thermocouple spot welded to the side of the cartridge, the capsule and packing was introduced

and the cap screw set in place and screwed down. On the first test the cartridge sealed in this way was found to leak to a slight extent. This was due to the technique followed in the sealing operation. After test 18 the covering became amalgamated accidently by mercury which had been raised too high in the cylinder overflowing into the cartridge reservoir. It was noted that the solder joint had begun to dissolve in the mercury. To see if this had any beneficial effect on the seal, test 19 was made and the cartridge found tight as far as could be determined. This suggests that a possible low melting amalgam might be used in place of solder as sealing agent but no further tests were made in this direction.

22. The cartridge was opened and capsule No. 36 resealed with solder in another cartridge. This cartridge was tested after some delay due to a breakdown of the counter apparatus requiring a replacement of the counter tube. This and two further tests could not definitely establish any radon leakage whatever.

23. The technique of making a seal in the radium cartridge which was found best consisted of the following steps:

(a) tinning the cap screw and the lower end of the cartridge body by dipping in a heated steel cup partly filled with solder and flux after dipping parts previously in flux made of Zinc and ammonium chlorides mixed in ratio of 65 : 35 with 100 parts water.

(b) fitting the cap screw to body to insure starting of the cap screw in the sealing operation.

(c) mounting cartridge body top down in the furnace vise and loading capsule with asbestos packing (or space fillers) after bringing cartridge body to temperature above 600° F setting in cap screw and tightening down.

(d) replacing steel solder cap in furnace and placing cartridge base below liquid level. If any pores exist air is forced out of the cartridge while submerged. When this ceases cartridge is removed, cooled in air, dipped again, and finally cooled and cleaned by polishing on a lathe with file and emery paper.

24. During the process of these tests a chemical analysis was made on the material of a radium capsule furnished empty as part of a recent contract for radium. (Navy Contract N1735-4035, 1940). The analysis obtained showed that zinc is present in the solder used to make the joints of the silver capsule while no zinc is present in the material of the body of the capsule. The analysis obtained for the latter was 89.6% Ag., 9.6% Cu. or approximately 90% Ag. 10% Cu. for an 0.15g sample. The flat bottom of a capsule weighing 0.15g give on analysis 0.3 mg. Zn. From this and the dimensions of the cartridge it may be estimated that the silver solder in the joint contains at the least 10% zinc.

25. Plate 8 shows a cross-section in the vicinity of the mentioned above and a photo-micrograph of the section in the vicinity of the corner where the side and bottom of the capsule are joined. In this may be seen a line of dark inclusions tracing the course of the silver solder joint. The grains outlined by a network of darker constituents are the primary silver-rich solid solution crystals of the alloy while the dark constituent is either a Cu - Ag entectic mixture or the beta copper-rich solid solution of Ag in Cu. It is evident that precipitation has occurred within the grains of silver alloy which is to be expected from its composition. Whether or not the dark constituents in the junction is the entectic or some other materials cannot be said from the photo-micrograph alone. The high solid solubility of Zn in silver makes it unlikely that this is a zinc compound such as the beta-phase of the silver zinc system. Presence of silver or copper oxide inclusions are more likely. In any case this string of inclusions along the junction affords a zone of weakness for propragation of intercrystalline corrosion and cracking along the junction. The presence of Zn in solid solution will change the galvanic potential of the solder alloy to promote such corrosion.

D. Discussion of Results and Conclusions

26. Table I shows that of eleven radium capsules tested in a field trip only one of the entire number was found to be satisfactory and in four cases the leakage was observed to be quite pronounced. These figures are sufficient to warrant an examination at convenient times of all of the capsules used by the Navy for gamma radiography and a schedule for this purpose will be worked out.

27. It has been indicated above that the leakage of radon from these capsules ordinarily does not present any considerable hazard to the radiographic personnel handling this radium but that there are cases in which danger may arise and any possibility of this happening should be reduced as far as possible. It has been shown above that time lost from service required for complete repairs of the radium capsule may be saved by enclosing the capsule in a sealed steel container. There is one drawback to this expedient that may be pointed out. The radon leaking from the silver capsule (See Plate 6) will occupy the entire cavity in the steel cartridge and will come to equilibrium with the radium salt in the capsule. This builds up an effective source of considerably larger dimensions than the original capsule. Plate 6 shows the effect that this increase in source size has on the radiographic definition by means of the width of the penumbral zones arising from both the capsule and the entire cartridge cavity. Thus the width of the penumbral edge arising in the shadow from defect A is given by aa' for the capsule itself and by bb' for the cartridge. It may be appreciated that this may seriously impair the definition obtained especially in the case of a small defect such as illustrated at B. This difficulty can be met in one of two ways (1). By using such cartridges at larger working distances than ordinarily

employed to compensate for the increase in effective source size and (2) by construction of the cartridge so that practically the entire internal volume of the cartridge is occupied by the capsule except for a small amount required for packing to cushion the capsule. Since farther damage to the capsule once it sealed within the steel cartridge will not effect its use, even the cushioning material may be dispensed with.

28. Returning to the construction of the silver capsule itself the following suggestions for its improvement may be made on the basis of the findings of this report. First of all tests made on a number of representative capsules have shown that the majority of the radium capsules leak to a greater or less extent. The few exceptions show that a substantially leak proof capsule is occasionally made with the technique followed. It has previously been recommended to the Bureau of Ships that future contracts stipulate a 1 mm wall thickness in place of the $\frac{1}{2}$ mm wall thickness used heretofore. To further increase the quality of the silver capsule it may be suggested that the use of silver solder joints be eliminated completely by spinning the cartridge in a single piece of silver alloy leaving only a small opening to be finally sealed with silver solder. This method could also be used to give an approximately spherical shape to the radium capsule which would reduce its effective source size. A further suggestion may be made in that the silver capsule be replaced by a steel capsule which may be made of sufficient dimensions to withstand all conceivable mechanical abuse and in which the radium sulphate salt is permanently sealed by welding. Such capsules could be built in sizes approximating the steel cartridges now in use. A conceivable drawback would be in possibility of damage to external eyelets but even these may be machined integrally with the cartridge body and made of such strength that little possibility if any of breakage will exist.

29. The analysis and photo micrograph made on the silver alloy capsules have shown that there is a definite tendency for corrosive action to take place in the joints of the silver capsule and that the silver solder used in making these seals contains a conceivable amount of zinc. Aside from the possibility of cracking in the solder joint after the capsules have been made there is the possibility that much of the leakage is due to an imperfect bonding in the joints leading to opening of the joints after the capsule has been in service for some time.

30. The tests made in this report have shown that it is possible to seal a leaking radium capsule in a steel container so that it may be used in radiographic inspection until a convenient time for repair arrives. The effectiveness of seals made by purely mechanical means such as screw joints with gasketing materials is questionable. The results of Table II indicated that most of these tried failed and that in one or two cases where a seemingly tight cartridge was obtained. Lead and even copper gaskets can give in the course of time, reducing tightness of contact in the joint. The most reliable method of sealing consists in solder joining the cap screw to the cartridge. Even this operation must be carried out with considerable care as may be noted

from Table II.

E. Recommendations

31. It is recommended that future radium sources purchased for use in Navy gamma radiography be enclosed in silver alloy containers having a minimum wall thickness of one millimeter and made as nearly free of joints as possible by spinning the cartridge from a single piece of material. If improvement along this line does not result attention should be turned to the use of steel cartridges in which the radium salt is sealed by welding.

32. Navy radium capsules now in use should be systematically exchanged and rotated so that inspection and temporary repair can be made to these at the NRL by sealing these leaking capsules in steel cartridges using a solder joint to complete the seal. The cavity or available space within these cartridges should be no greater than just necessary to contain the enclosed capsule.

TABLE II

Summary of Test results on Methods of Sealing Radium Cartridges

Test No.	No. of Capsule	Method of Sealing	Results
1	20	Flat lead gasket .006"	Test at atm. pressure. No definite leakage.
2	"	"	Prolonged test under vacuum. No definite leakage.
3	"	"	"
4	"	"	"
5	36 + 37	No seal Cartridge as received.	Strong leakage.
6	20	Flat lead gasket .006"	Prolonged test. Slight leak possible.
7	36	Flat copper gasket with V groove in cartridge body.	Test at atm. press. No definite leakage.
8	36	Flat copper gasket with V groove in cartridge body	Vacuum test. Slight leak possible.
9	36	Flat lead gasket .006"	Vacuum test. Pronounced leakage.
10	36	Copper gasket Double V groove.	Vacuum test. Considerable leakage.
11	36	Same as (10). Cartridge tightened.	Vacuum test. Definite leakage.
12	36	Thick lead gasket. .015" Double V groove.	Vacuum test. Slight but definite leakage.
13	36	Inside recess filled by solder wire gasket.	Vacuum test. No leakage observed.
14	36	Same as (13)	Vacuum test. Small leakage detected.
15	36	Inside recess fitted by solder wire gasket.	Vacuum test. Prolonged leakage definite.
16	36	Regular cartridge with lead wire around thread recess.	Vacuum test. Leakage definite.
17	36	Same as (16). Tightened	"
18	36	Cartridge sealed with special tin solder.	"
19	36	Same as (18). Accidentally amalgamated.	Vacuum test. No definite leakage.
20	36	Cartridge resealed with sp. solder.	Vacuum test. No leakage.
21	36	Same as (20)	Vacuum test. No leakage.
22	36	"	" "

PLATE

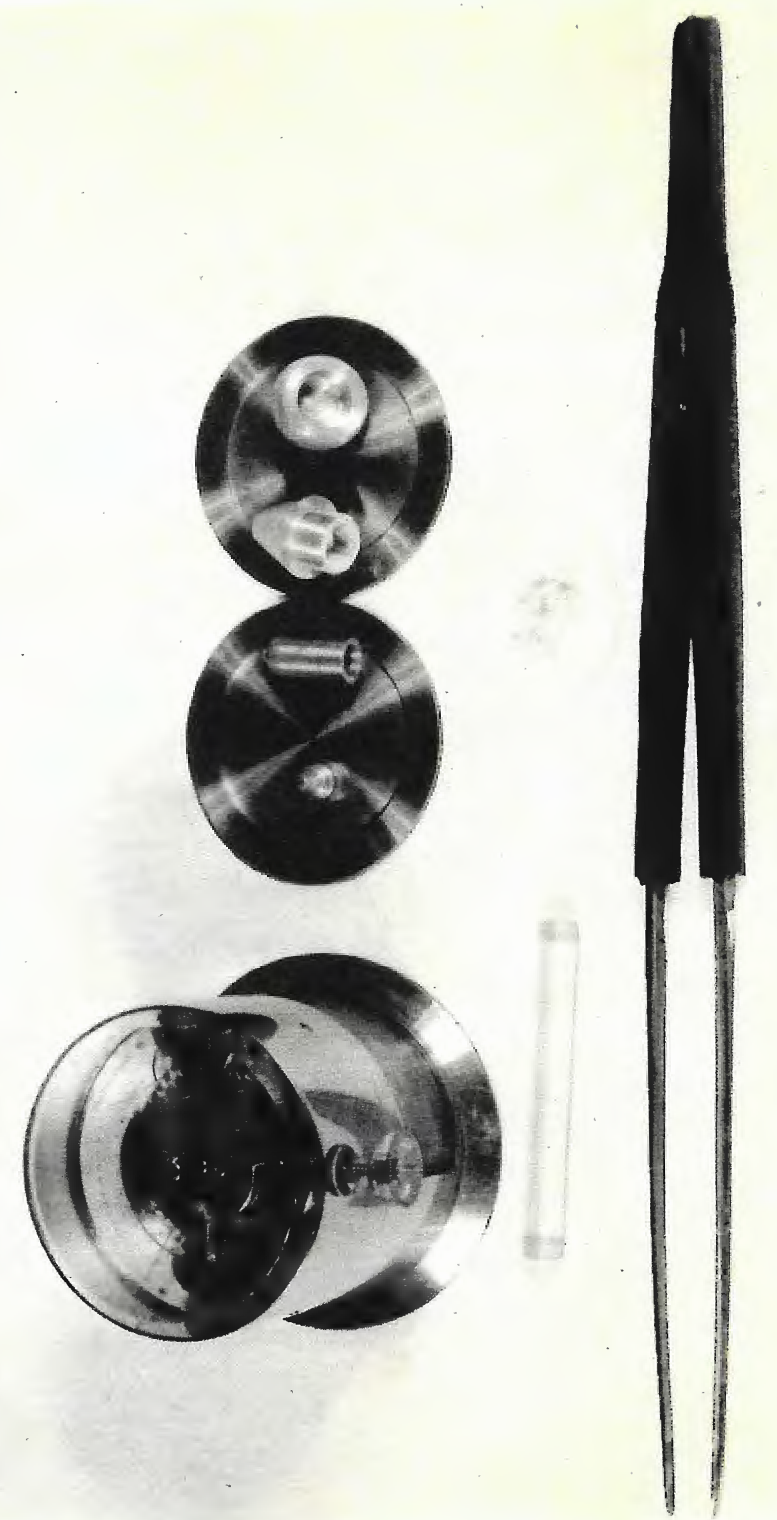


PLATE 2

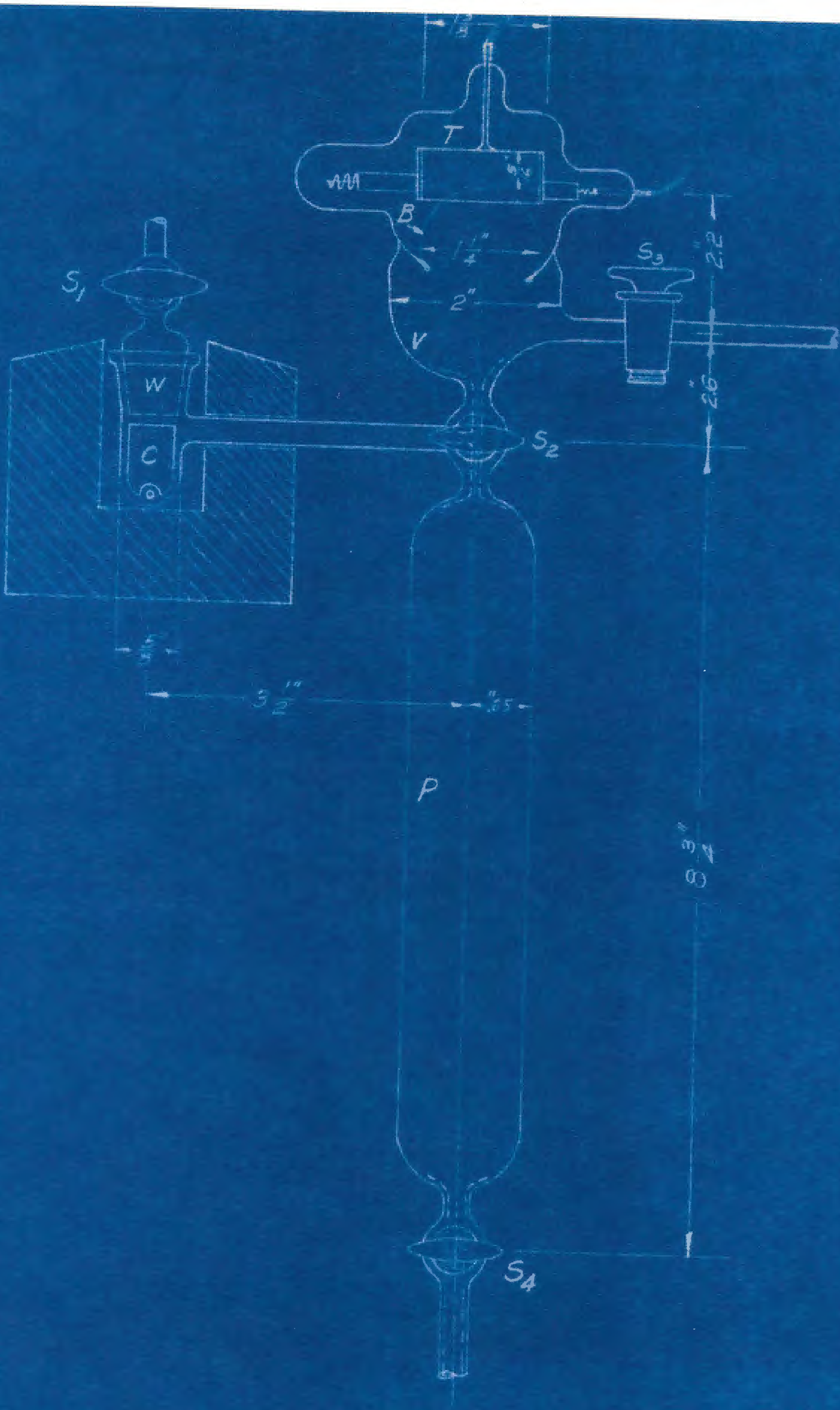


PLATE 3

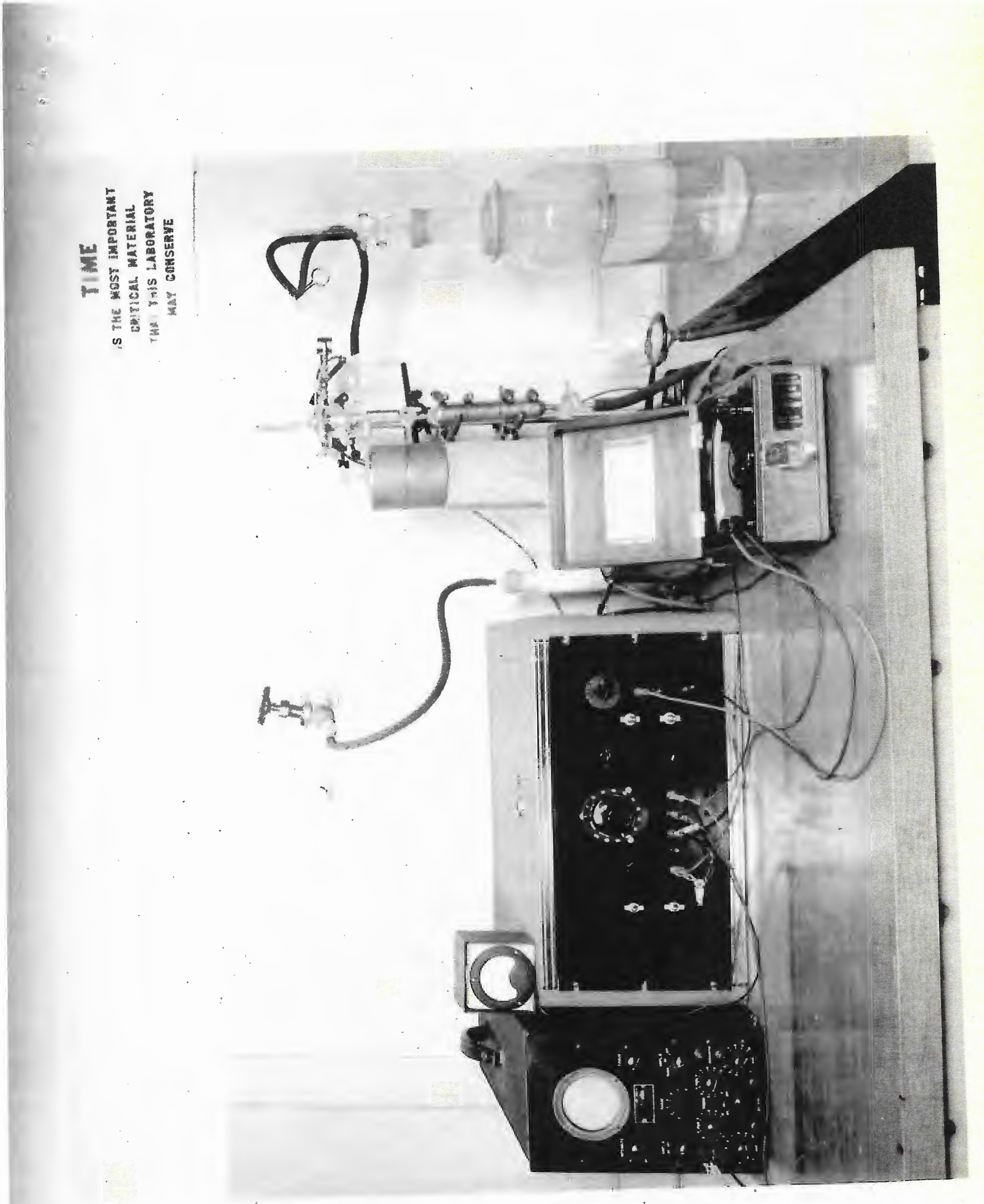
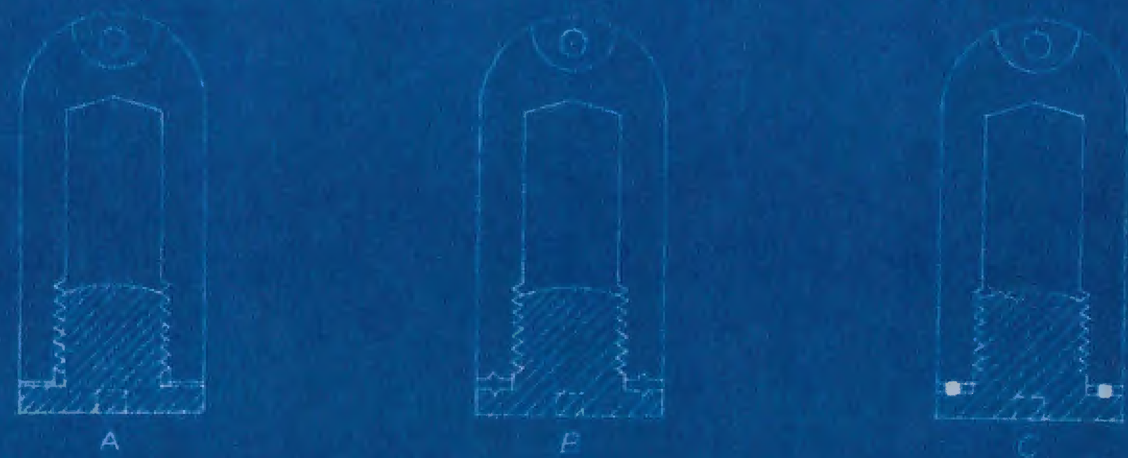
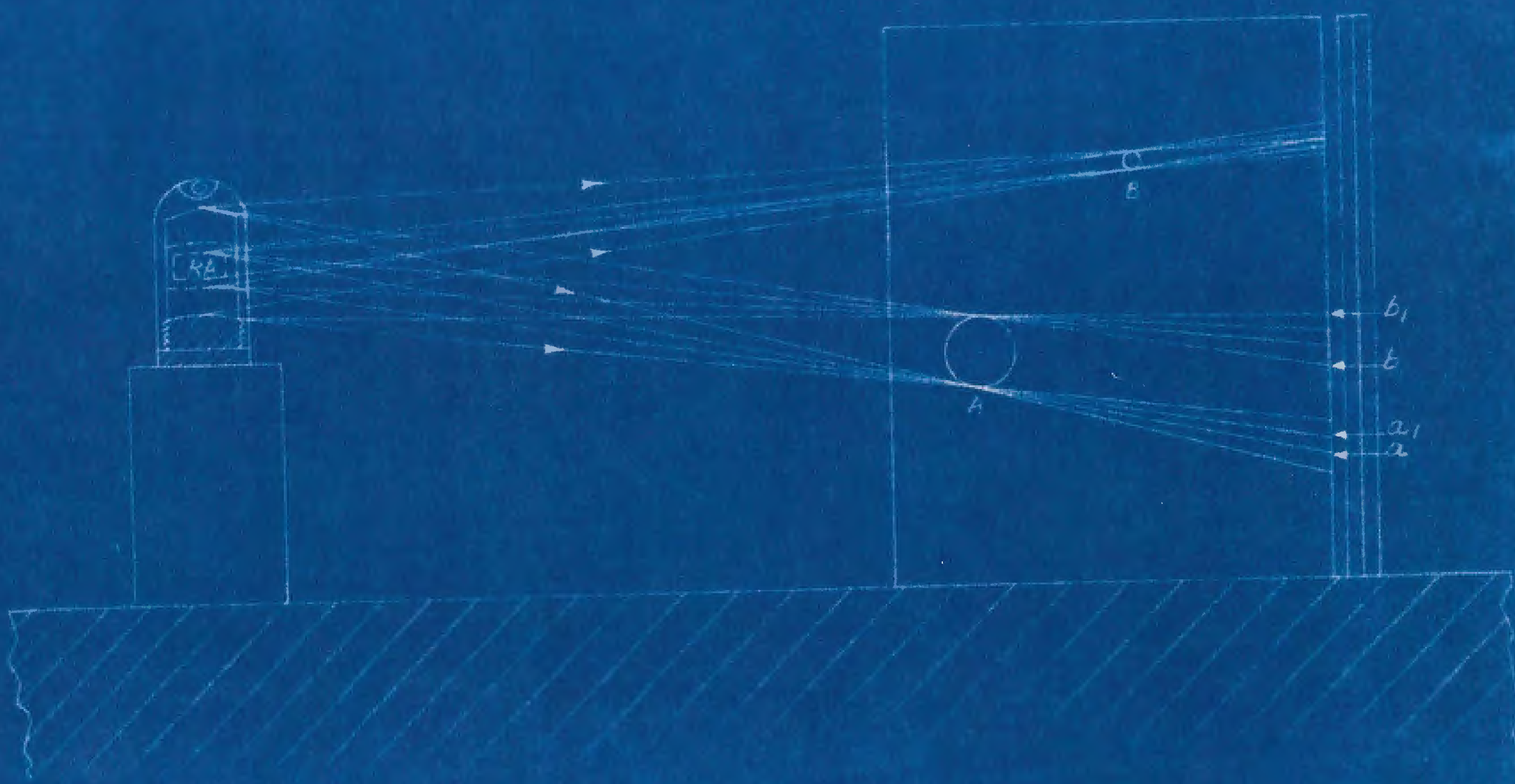

TIME
IS THE MOST IMPORTANT
CRITICAL MATERIAL
THAT THIS LABORATORY
MAY CONSERVE

PLATE 4



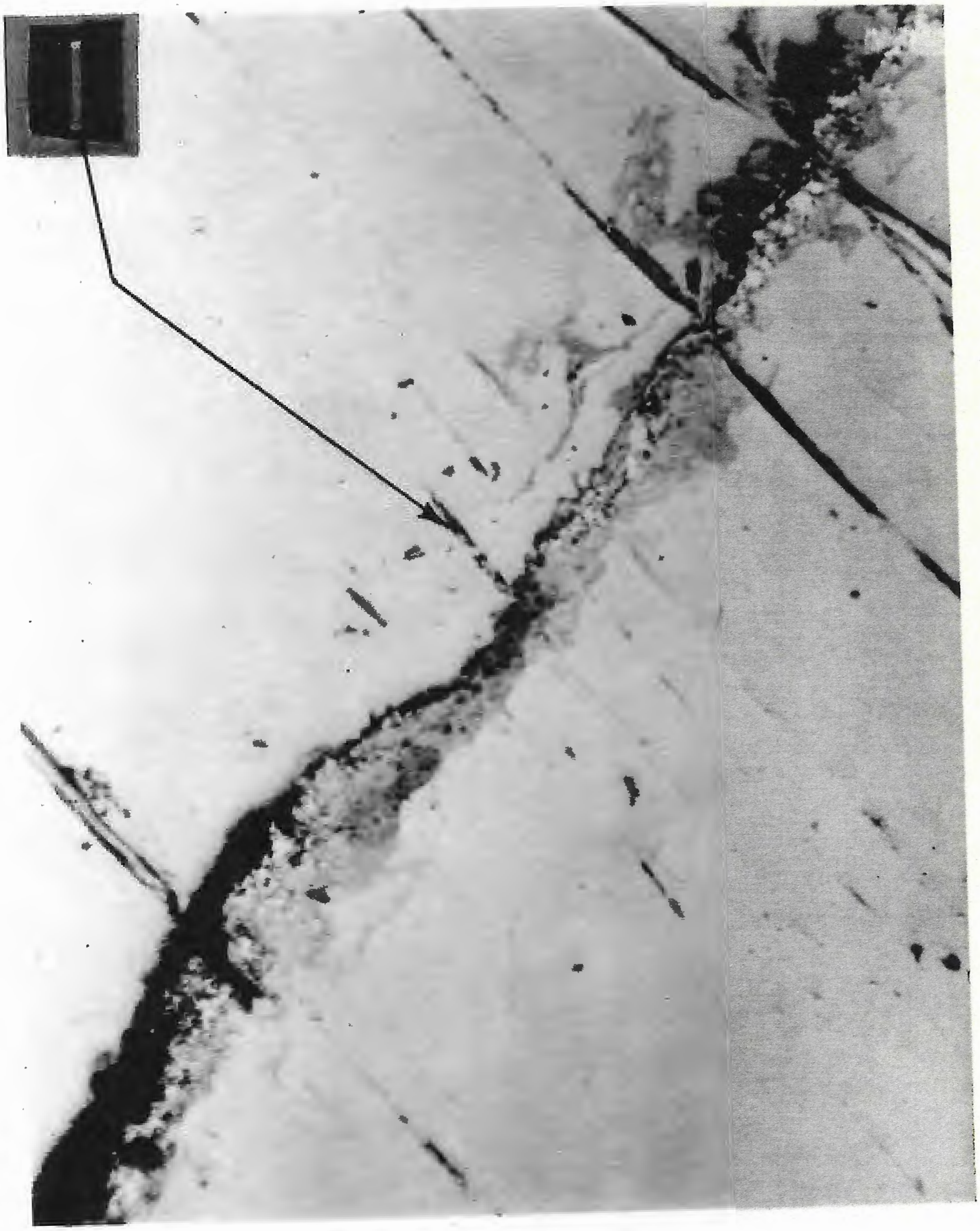
METHODS OF GASKETING USED IN TEST CARTRIDGES

PLATE 5



EFFECT OF RADON LEAKAGE ON RADIOGRAPHIC DEFINITION

PLATE 6



PLATE

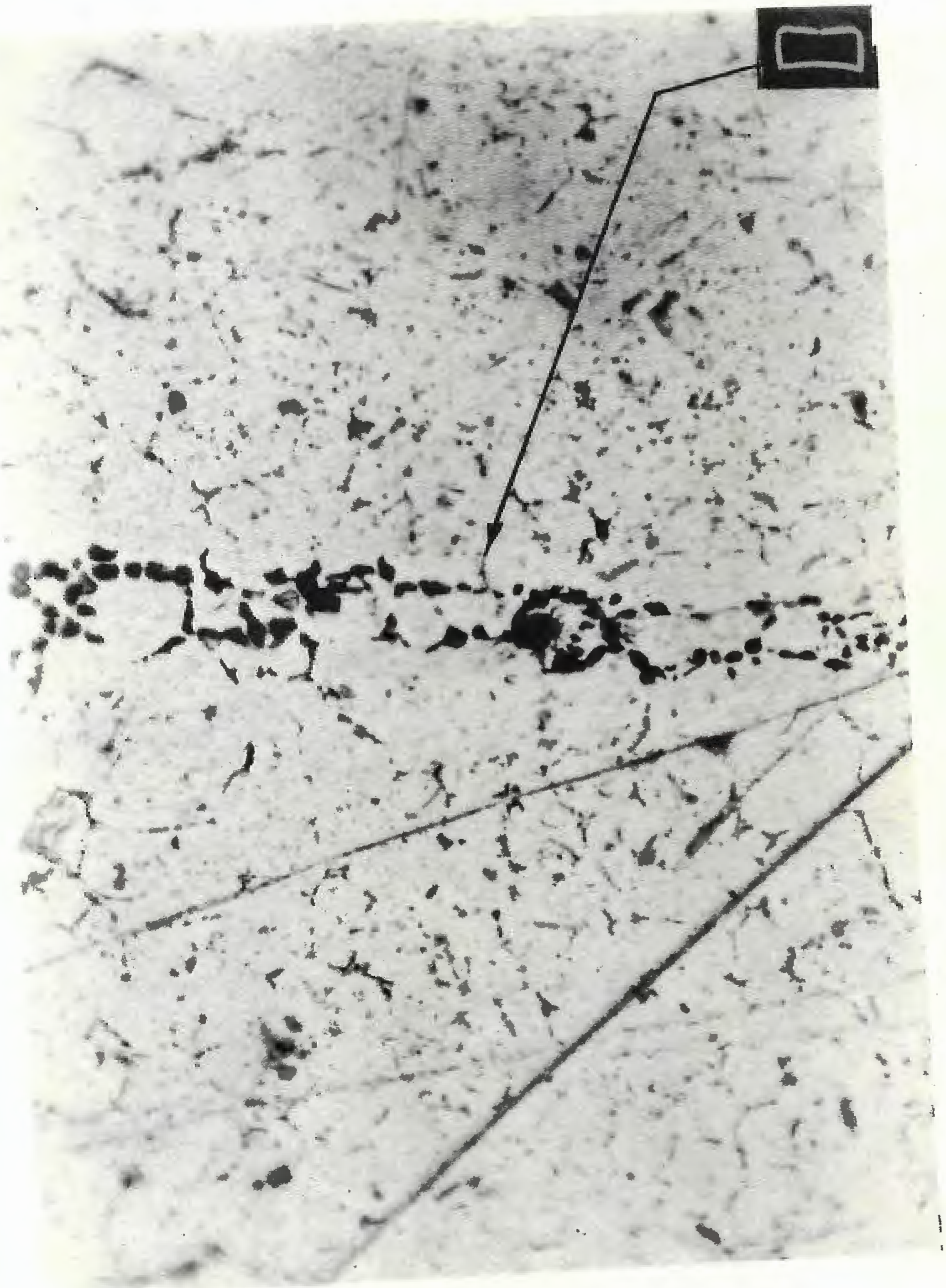


PLATE 8