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THE OCD-D-103: A NEW HIGH-STABILITY BETA/
GAMMA GM TUBE

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THE OCD-D-103
A NEW HIGH-STABILITY BETA/GAMMA GM TUBE

BY
JOSEPH G. JOHNSTON

FINAL REPORT ON
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Abstract

Replacement GM tubes for the Civil Defense CD V-700 Portable Survey Meter were not always compatible with every instrument even though both tube and instrument met the specification requirements. To alleviate this problem, a comprehensive specification was written for a GM tube based upon desirable features rather than demonstrated performance. This report details the engineering effort which produced a tube to meet the formidable new specification.

TABLE OF CONTENTS

Section Title	Page
Abstract	iii
Introduction	1
The CD V-700	3
Performance of the 6993	4
Replacement Parts Procurement and the Retrofit Program	6
Performance of the 6993 in ORNL Circuit	8
Analysis of Basic Problem	12
After-Pulsing	13
Plateau Stability	14
Analysis of Current Pulse	15
Engineering Effort Toward Solutions	19
Performance of the OCD-D-103	28
OCD-D-103 Mechanical Construction	35
Conclusion	37
Bibliography	38
Appendix: Final OCD-D-103 Specification	

LIST OF ILLUSTRATIONS

Figure	Title	Page
1.	Conventional GM Tube Test Setup	4
2.	6993 Plateau Curve as Measured in Circuit of Figure 1	5
3.	6993 Plateau Curve with ORNL Circuit. 5 mR/h. No Prior Tests for Several Hours	10
4.	6993 Plateau Curve with ORNL Circuit. 50 mR/h. Immediately Following 5 mR/h Test	10

LIST OF ILLUSTRATIONS (CONT'D.)

Figure	Title	Page
5.	6993 Plateau Curve with ORNL Circuit. 5 mR/h. Immediately Following 50 mR/h Test	11
6.	Hysteresis Test -- 6993 with ORNL Circuit	11
7.	6993 Plateau Curve Composite	14
8.	Typical 6993 Pulse Shape, Conventional Measuring Circuit . . .	15
9.	Test Circuit for Measuring Current Pulse.	16
10.	6993 Current Pulse Shape at Several Different Voltages	17
11.	D-103 Plateau Curve with ORNL Circuit. 5 mR/h. No Prior Tests for Several Hours	32
12.	D-103 Plateau Curve with ORNL Circuit. 50 mR/h. Immediately Following 5 mR/h Test	32
13.	D-103 Plateau Curve with ORNL Circuit. 5 mR/h. Immediately Following 50 mR/h Test	33
14.	Hysteresis Test -- D-103 with ORNL Circuit	33
15.	D-103 Plateau Curve Composite	34
16.	OCD-D-103 GM Tube	35
17.	Cutaway View of OCD-D-103 GM Tube	36

Introduction

Before the advent of transistorized circuits, Geiger-Mueller tubes were traditionally measured with a load resistance of about one megohm and a coupling capacitor of 50 pf or less. The original OCD GM tube specification -- the OCD-6993 -- was based upon this kind of test procedure.

The experience gained over the years with the manufacture of self-quenching GM tubes showed that if the load resistance were reduced, the only ill effect was the reduction of the pulse amplitude. In an inverse manner, the same was true of increasing the load capacitance as for example by the use of a long cable to connect the tube to the counting circuit. This experience was primarily with the classic organically-quenched tubes such as the Victoreen 1B85, a tube which is still highly popular today.

Early work on halogen-quenched GM tubes indicated that similar performance could be expected of them, with the added advantage that much longer tube lifetimes could be achieved. The primary reason for this is that the halogen does not change its chemical properties as a result of its use as a quenching agent.

With the development of the CD V-700 portable Geiger Counter for Civil Defense use, it was logical to employ solid state circuitry in order to conserve battery life and to reduce physical size. The requirements for long life seemed to indicate that a halogen-quenched Geiger tube would be most advantageous. A commercially-available tube, the type 6993, was chosen because its physical size, counting rate, and beta/gamma sensitivity met the requirements of the device.

Because of the assumption stated earlier that there was basic similarity between halogen-quenched and organically-quenched tubes, the experience with the earlier tube types was used in the development of test specifications for the 6993

tube in its application in the CD V-700. This assumption, unfortunately, was incorrect.

While the CD V-700/6993 combination has proven to be a highly reliable and useful instrument over the years, the problem of replacement parts has been compounded by the fact that the 6993 really does not have a plateau which is long enough to cover the wide range of operating voltages found in the CD V-700 instruments in the field, even though the tubes do have a sufficiently long plateau when measured by the classical method (1 megohm-50 pf load).

Recognizing the compatibility problem, the Office of Civil Defense developed, with the aid of the Oak Ridge National Laboratory, a comprehensive new specification for a replacement GM tube -- the OCD-D-103. The specification was written around all the desirable features of a hypothetical tube which had never been produced, but which, if feasible, would increase the reliability, accuracy, and useful life of the inventory of CD V-700's in the Civil Defense stockpile.

This report describes the engineering effort which went into the development of this tube -- from the "hypothetical" stage to the production stage.

The CD V-700

The CD V-700 is a low cost, portable survey instrument which was designed originally for low-level beta and gamma monitoring following a nuclear explosion. The basic requirements were simplicity, reliability in the field environment, and low cost. A commercially-available thin-walled halogen-quenched GM tube -- the type 6993 -- and a simple battery-operated count rate circuit were used to drive a meter and a headphone. This high-sensitivity device covers the range from about 0.1 mR/h to 50 mR/h with a basic accuracy of $\pm 15\%$, making it useful in a wide variety of monitoring applications.

Tens of thousands of instruments were procured from several different companies. Each company designed its own circuit, so that internally the CD V-700's vary considerably, even though the basic performance is similar. In conjunction with the ongoing Civil Defense instrument maintenance and calibration program, the CD V-700 has been a highly successful device.

Performance of the 6993

The 6993 GM tube was originally designed and built by the Anton Corporation for portable survey use. Its widest application was, of course, in the CD V-700. The commercial specification for the 6993 covered mainly the physical dimensions, the plateau length, the dead time, and a few other parameters. The Office of Civil Defense specification broadened this considerably to include environmental performance requirements. In all cases, the tubes were tested by the conventional method which had been in general use for years. This method consisted of a high voltage power supply, an oscilloscope, a scaler, and a radioactive source. The components were arranged according to Figure 1.

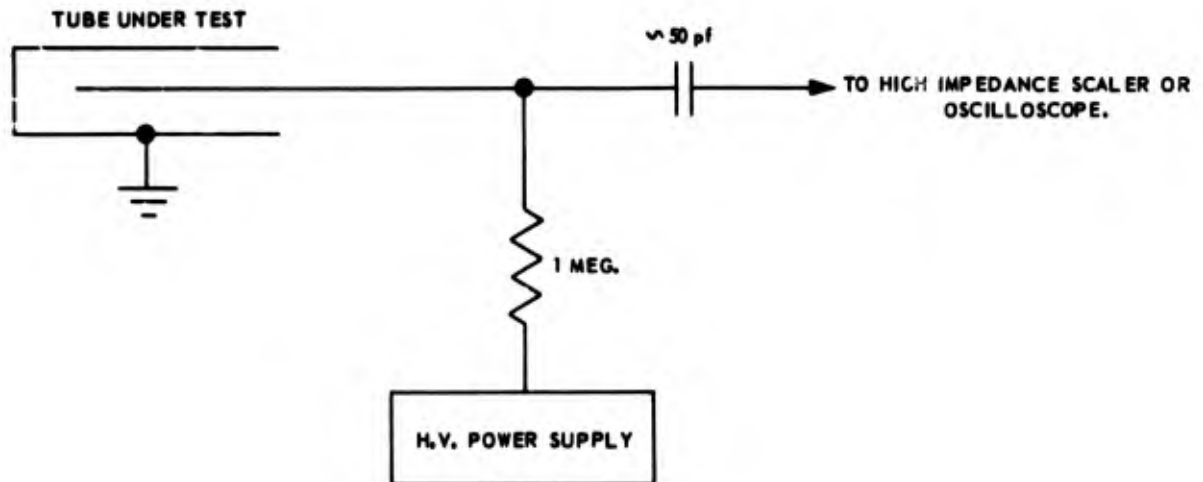


Figure 1. Conventional GM Tube Test Setup.

The starting voltage was defined as the voltage at which one-volt pulses appeared at the input to the oscilloscope. For the 6993, this was required to be 860 volts or less.

The operating plateau began at the starting voltage and continued upward until a substantial degree of "after-pulsing" was encountered. The plateau requirement was 860 to 920 volts, although experience indicated that a much wider range was actually typical for the tube.

Figure 2 is a typical plateau curve for the 6993 tube measured in the conventional circuit.

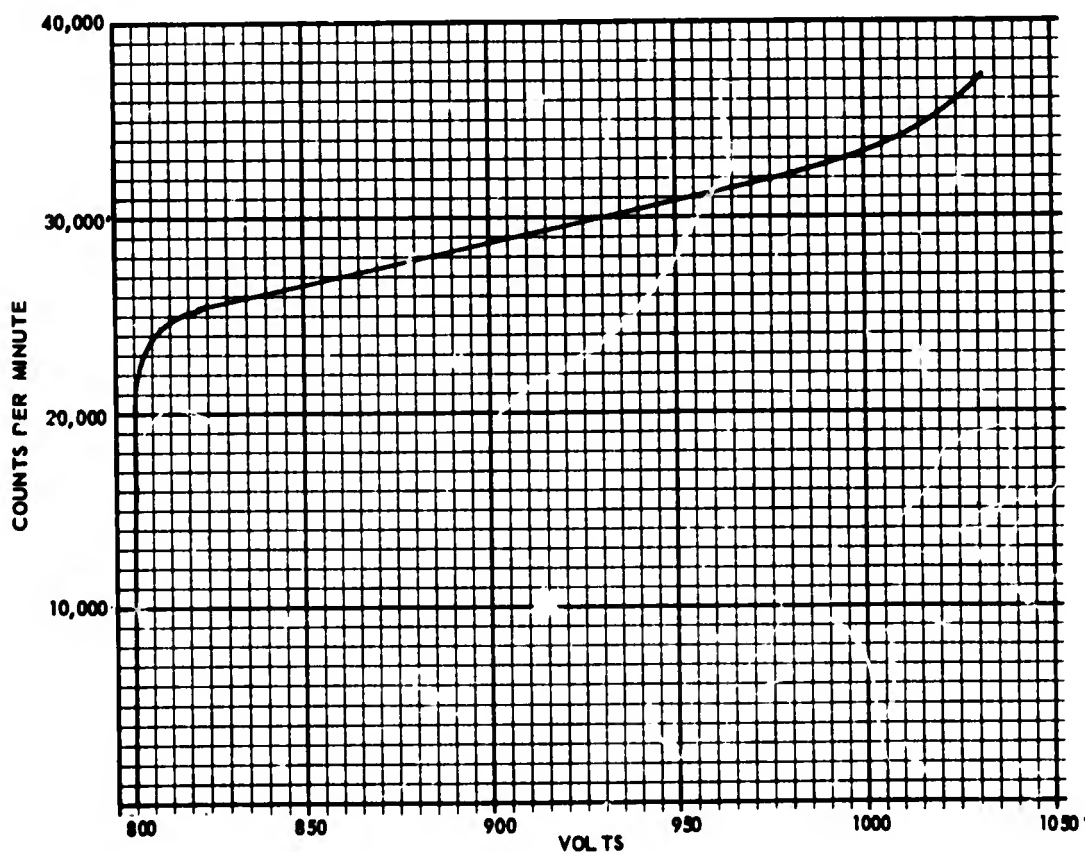


Figure 2. 6993 Plateau Curve as Measured in Circuit of Figure 1

Replacement Parts Procurement and the Retrofit Program

An analysis of the Civil Defense stockpile of radiological survey instruments, including the CD V-700, showed that the basic design and construction were good, but that improved performance and longer life could be achieved if tighter specifications were written for replacement and spare parts. Programs undertaken by Battelle Memorial Institute, Stanford Research Institute, Vitro Laboratories, Oak Ridge National Laboratory, Victoreen, and others, under the direction of OCD's Nucleonics Division, resulted in new specifications for components which have materially upgraded the CD instruments at a cost far less than new instruments. One of the new specifications to come out of this program was the OCD-D-103 tube.

The OCD-D-103 specification called for a tube which was basically similar to the 6993, but with a long plateau requirement to cover the range of voltages in the CD V-700's in the field. The conventional testing procedure was unchanged. It was felt that the 6993 could meet the D-103 specification with greater care in manufacturing and testing, and if a smaller yield could be tolerated.

To meet the new plateau specification, a 2 megohm resistor was inserted in the anode lead inside the base of the tube to aid the quenching mechanism. This procedure has long been accepted for halogen-quenched tubes. In fact, many commercial GM tubes require such a resistor mounted directly to the tube anode in order to operate at all. The D-103's manufactured this way had long, flat plateaus and good stability, but did not perform well at all in the CD V-700 due to its low input impedance.

This compatibility problem led to the development by the Oak Ridge National Laboratory of the ORNL Q-2903B interface circuit to be used between the tube under test and the scaler, power supply, and oscilloscope, to simulate the worst-

case loading conditions encountered in the field. This interface circuit has an input discrimination level of 500 mV, and an input impedance of approximately 4000 ohms shunted by a cable capacitance of approximately 100 pf for pulses which are not large enough to trigger the circuit. As the input circuit comes into conduction, the impedance decreases in a non-linear fashion. The interface is referred to as the "ORNL Circuit" in this report.

Oak Ridge also improved further on the OCD-D-103 specification, giving careful consideration to requirements for such important items as stability, environmental performance, and quality control. While no tubes had been manufactured which met all of the requirements of this very exacting specification, it was agreed that substantial improvements in instrument performance would be realized if such a tube could be built.

A copy of the final OCD-D-103 specification is included in the Appendix.

Performance of 6993 in ORNL Circuit

A testing program was undertaken to evaluate the performance of the 6993 tube with the low-impedance ORNL circuit. In order to gain as much insight as possible, it was decided to use a graphic testing approach. Plateau curves for a large number of 6993's were drawn on an automatic plotter consisting of a programmable high-voltage power supply, an X-Y recorder, and the ORNL interface circuit.

The testing procedure was as follows:

1. Plot a plateau curve in a field of 5 mR/h ^{137}Cs gamma radiation, starting at 800 volts and increasing slowly to 1050 volts.
2. Plot a second curve immediately, at 50 mR/h.
3. Repeat step 1.
4. With HV at 990 volts, measure the count rate at 5 mR/h. Expose tube to 5 R/h for 30 minutes. Repeat the 5 mR/h measurement.

These tests, performed on a large number of 6993's, both old and new, pointed out a number of interesting and puzzling characteristics. Figures 3 through 6 are representative plots, redrawn for clarity, which illustrate these characteristics. The major shortcomings of the tubes, when interfaced with the ORNL circuit, were determined to be:

1. Short plateau -- as low as 40 volts in the relatively "flat" region.
2. Starting voltage, V_s (that anode voltage at which pulses are of sufficient amplitude to begin triggering the ORNL circuit), which drops as much as 25 or 30 volts after the tube has been counting. With some tubes, V_s also varies from day to day.
3. Non-reproducible count rate -- usually called "short-term instability".

Variation from 5% to 15% between trials.

4. Steep plateau slope.
5. Excessive hysteresis - i.e., after a 30 minute exposure to 5 R/h, the response at 5 mR/h is non-reproducible, varying as much as $\pm 25\%$.
6. The plateau at 50 mR/h is usually much longer and flatter than at 5 mR/h.

A look at the plateau curves shows the poor plateau, the variation in counting rate, the shift in starting voltage, and so on. These tests, using a program rate of about 10 volts per minute, took about 25 minutes each to run.

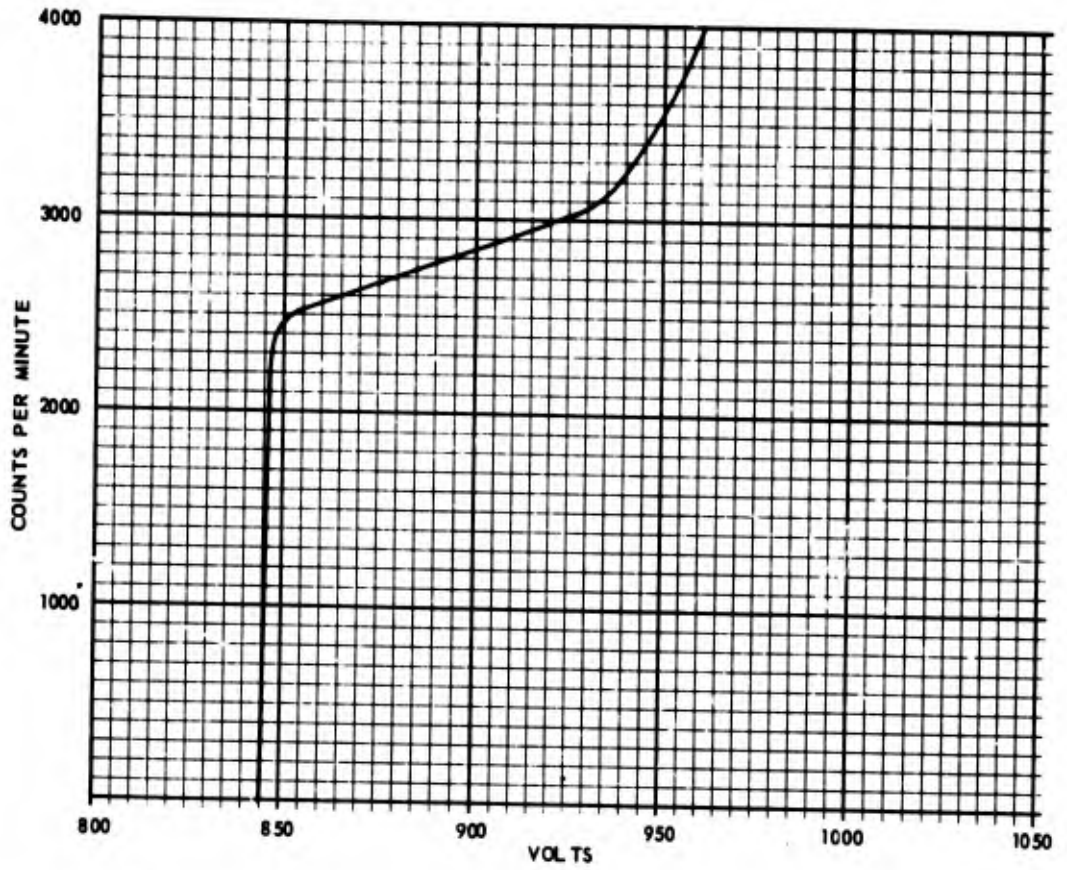


Figure 3. 6993 Plateau Curve with ORNL Circuit. 5 mR/h
No Prior Tests For Several Hours

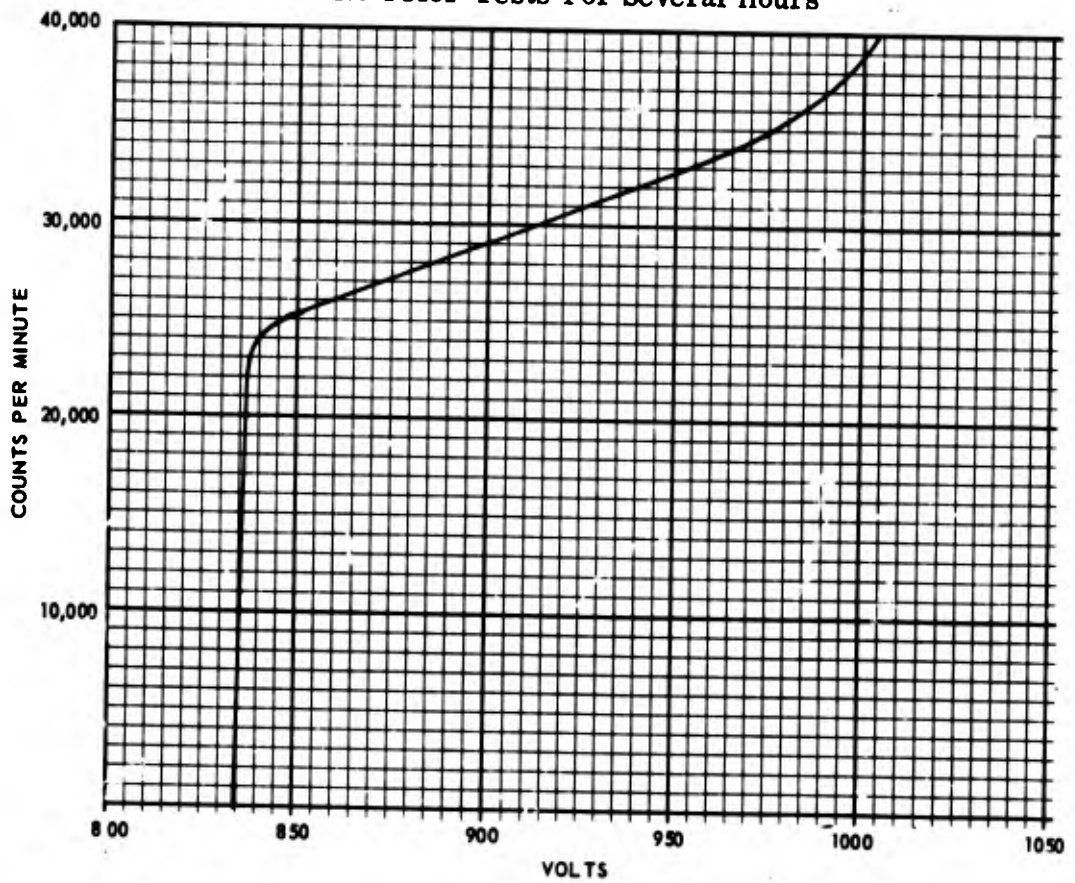


Figure 4. 6993 Plateau Curve with ORNL Circuit. 50 mR/h
Immediately Following 5 mR/h Test

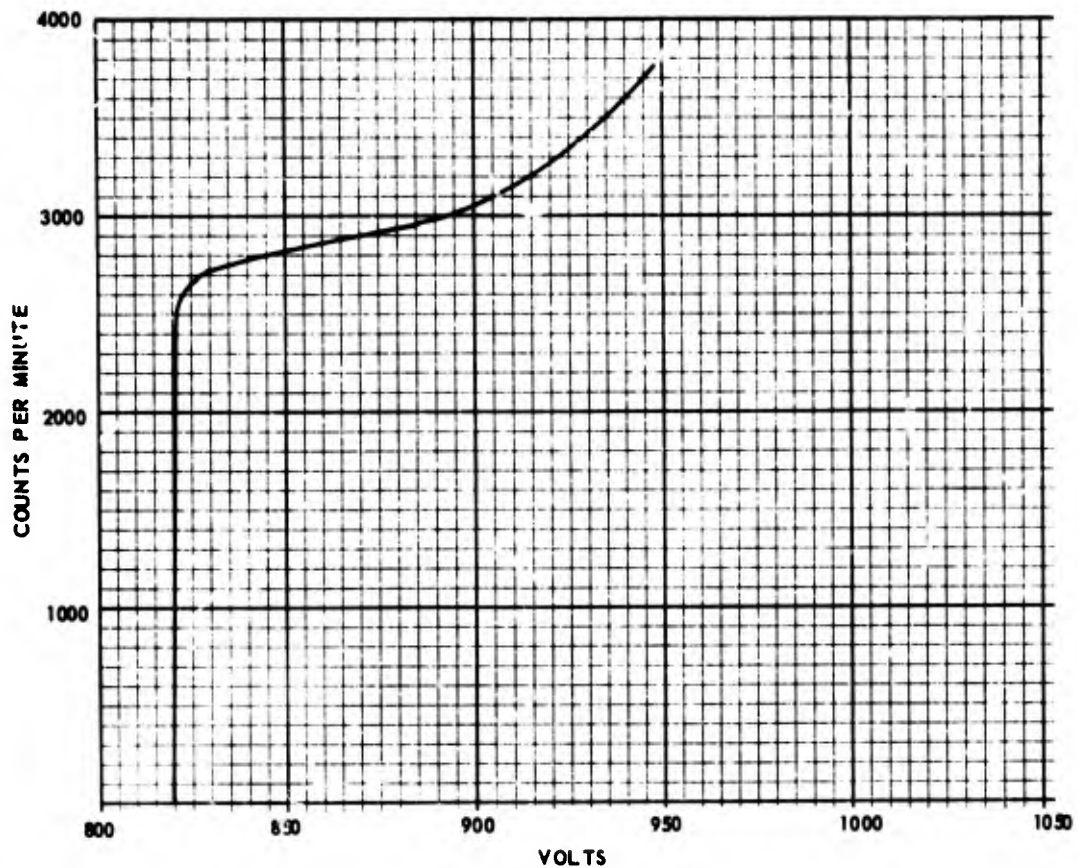


Figure 5. 6993 Plateau Curve with ORNL Circuit. 5 mR/h Immediately Following 50 mR/h Test

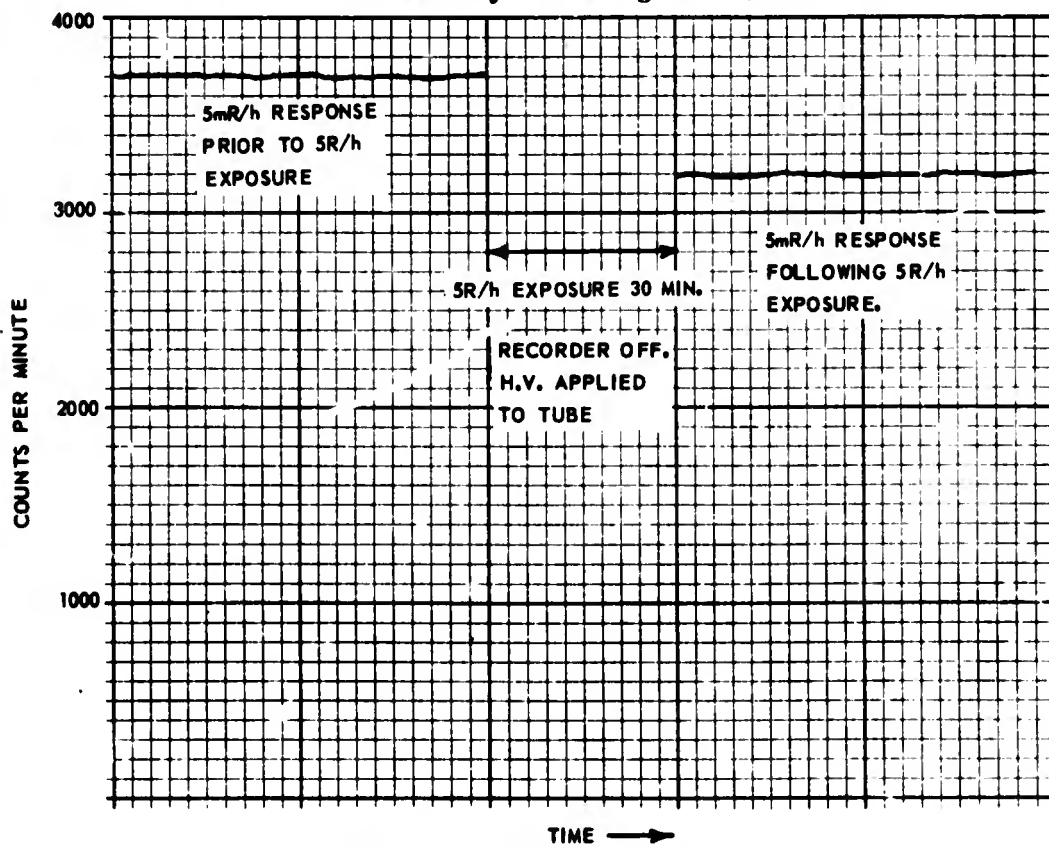


Figure 6. Hysteresis Test -- 6993 with ORNL Circuit

Analysis of Basic Problem

The real difference between the existing 6993 and the "hypothetical" D-103 is that of testing procedures. The 6993 is tested in a high impedance circuit. The quenching process is helped along by the circuit itself. As an avalanche occurs, current flows through the tube from the power supply and a voltage drop is developed across the load. This reduces the voltage at the anode, reducing the gradient inside the tube, and tends to help extinguish the discharge. Most halogen-quenched tubes rely on external series impedance in this manner.

The D-103 requirements are much more stringent -- the low impedance load makes it mandatory that the quenching mechanism be complete within the tube itself, with no reliance on the external circuit for support.

The next several sections of this report detail the individual problems which exist when a halogen-quenched tube is operated into a low impedance, and the engineering effort which went into the solution.

After-pulsing

An after-pulse is a spurious count generated following a normal count produced by external ionizing radiation. After-pulses occur after the GM tube dead time, and are indistinguishable from ordinary pulses.

This is a serious problem, of course, if a long, flat plateau and good stability are to be achieved.

After-pulses are the result of excited atoms or molecules which are deionized by collisions, and by the neutralization of positive ions.¹ The reduction of after-pulses is one of the most critical considerations in good GM tube design, and is related to the use of chemically pure materials in the construction of the tube and to the elimination of sharp points in the high gradient region. In addition, high cathode work function will reduce the likelihood of secondary electron emission from the cathode surface, reducing the chance for after-pulsing.

But regardless of the care used in manufacture, all tubes exhibit serious after-pulsing above a certain voltage which is generally considered to be the upper limit of its usable plateau. At this voltage, the charge per pulse is so high that the quench gas is no longer adequate to extinguish the discharge. In organically-quenched tubes, this voltage is independent of the load connected to the tube; in halogen-quenched tubes, it is a strong function of the load resistance and capacitance.

This load dependence is the primary reason that the 6993 performs well in a high impedance test circuit such as the conventional circuit of Figure 1, but is unstable and has a short plateau in the low-impedance ORNL test circuit.

¹D. Srdoc, "Gas Discharge Mechanism and Properties of Halogen-Quenched Counters," Nuclear Instruments and Methods, 99 (1972), p. 329.

Plateau Stability

The lack of stability in the 6993, when measured in the ORNL circuit, can be seen to be primarily due to two factors.

- 1 . The slope of the second part of what appears to be a two-part plateau varies with time, counting rate, load, and probably other factors.
- 2 . The position of the entire plateau, even the more stable first portion, moves with respect to voltage.

These two effects are easily observed in Figure 7, which shows the three plateau curves of Figures 3, 4 and 5, superimposed on one another.

The elimination of the second portion of the plateau was clearly the most important problem at hand. If the transition into a less stable region could be avoided, a longer plateau and greater stability could be achieved.

The shift in the plateau position is a problem especially in the case of short, steep plateaus. It would be minimized if the plateau were flat, so that the counting rate would not change, and if it were long, so that operation close to or below the starting voltage would not occur.

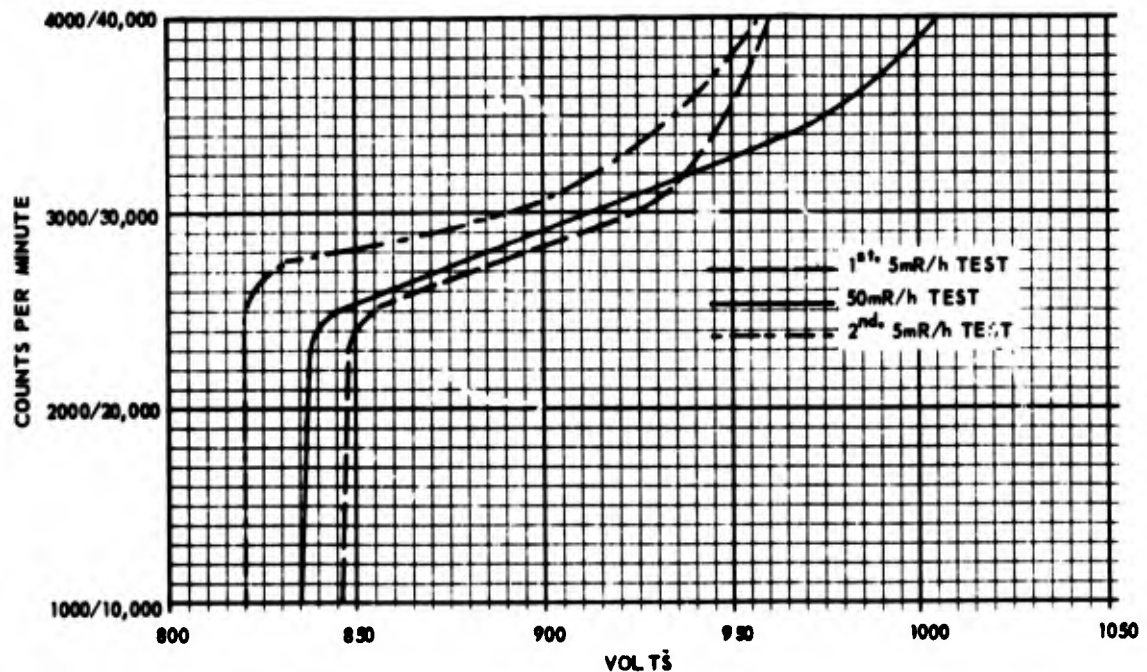


Figure 7. 6993 Plateau Curve Composite

Analysis of Current Pulse

All the tests performed on the 6993 indicated clearly that there were many problems. But very little light was shed on the nature of these problems as a result of these tests.

The most perplexing single deficiency in the 6993 was the plateau transition into a non-stable region. In an attempt to analyze this transition, a method was devised to enable the observation of the shape of the tube's current pulse.

The ORNL circuit is a good production tester for tubes to find out if they will work in a CDV-700. But it is not a research tool. It does not enable any study of pulse shapes because the pulses are shaped by the circuit.

The conventional circuit of Figure 1 does not enable any study of pulse shapes either, because the capacitance of the measuring device (approximately 50 pf) in parallel with the anode to cathode capacitance (typically 2 pf) increases the time constant so much that the true pulse shape is masked.

Figure 8 shows a typical 6993 integrated voltage pulse as measured in the conventional circuit. The pulse duration is of the order of 100 microseconds.

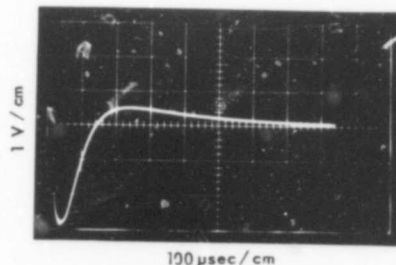


Figure 8. Typical 6993 Pulse Shape, Conventional Measuring Circuit

In order to determine the true current pulse shape, it is necessary to measure the tube current without affecting that current in the measuring process. Because this is difficult to do with any practical measuring circuit connected to the anode in the conventional manner, it was decided to measure the current at the cathode across a small resistance from cathode to ground. The anode circuit was still attached to the ORNL module to provide for the standard anode loading effects. Figure 9 illustrates the procedure used.

Early tests were performed with a 50 ohm resistor and approximately 100 pf of distributed capacitance. This series resistance is small compared with the 4000 ohm input impedance of the ORNL module, and the 5 nanosecond time constant is negligible. For the purpose of convenience, however, it became desirable to increase the size of the pulse available to the oscilloscope. The circuit presently used consists of a 500 ohm resistor shunted by approximately 100 pf.

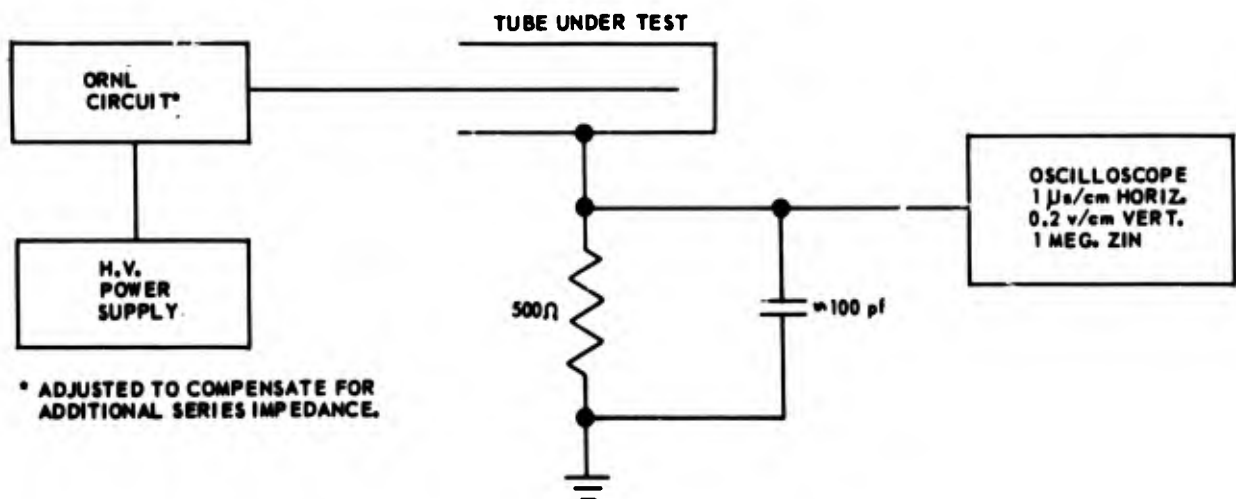


Figure 9. Test Circuit for Measuring Current Pulse

While it is true that the time constant and series resistance are no longer negligible, good correlation has been made between this and the earlier circuit.

Once a suitable circuit was devised, tests were made on various 6993 tubes over the voltage range from 860 to 990 volts.

Figure 10 shows the pulse shapes and heights observed for one typical 6993 tube at 860, 925 and 990 volts. This testing procedure shows that the actual current pulse consists of a large amplitude fast spike with a duration of about one microsecond, followed by a low amplitude, long time-duration tail. The slow component lasts for approximately 50 microseconds.

It is probable that the fast portion of the pulse results from electron collection and the slow portion from the movement of the positive ion sheath.²

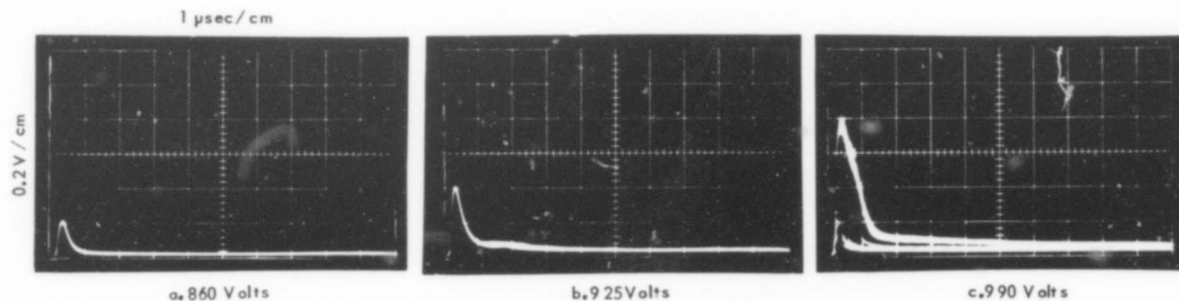


Figure 10. 6993 Current Pulse Shape at Several Different Voltages

It is not unexpected that the pulse height increases with increasing voltage. This is easily observed by the conventional test method of Figure 1. But the definite change in pulse shape--in particular, the appearance of a second pulse directly following the fast spike and superimposed on the slow component --

²H. N. Wilson, Oak Ridge National Laboratory, private communication.

above a certain voltage is the most notable aspect of this test.

An examination of the plateau curve for any particular tube brings out the most important point of all -- the voltage at which the plateau slope transition occurs is always the same as, or higher than, the voltage at which the pulse shape transition occurs.

It would appear, then, that if the pulse shape transition could be prevented, so could the plateau slope transition. In other words, if the pulse shapes could be kept "clean", a long, flat plateau could be achieved.

Engineering Effort Toward Solutions

Five separate, but related, phases of the engineering program were pursued, each providing part of the solution which led to the design of the OCD-D-103. In this section of the report, each phase is discussed briefly.

1. Cathode Treatment

The preparation of the cathode surface in a rare gas-halogen GM tube is critical from several standpoints. In order to preserve the hermetic seal, it is essential that the surface be compatible with the sealing glass which joins the cathode to the end insulators. The cathode surface must be impervious to halogen attack, even over very long periods of time. The surface must be free of contaminants which might outgas with time, or react with halogen, and must have a high work function to reduce the possibility of after-pulsing.

The 6993 cathode treatment involves a cleaning procedure followed by a firing technique at 500°C for 15 minutes in dry air. The coating thus formed is an oxide of the stainless steel which has been shown over the years to perform reasonably well. However, the presence of oxygen as a contaminant probably is responsible for some after-pulsing. In addition, the surface does not provide a perfect interface for the metal-to-glass seal at temperatures above 100°C.

A number of different firing techniques have been tried with poor results obtained for all except one specific procedure. This procedure is a very special form of hydrogen firing. A small, controlled amount of moisture metered into the hydrogen flow has been shown to produce a smooth, stable surface which meets all of the requirements for a good GM cathode. For this procedure to be successful, absolute cleanliness of the surface is essential.

The actual procedure involves several washing steps followed by firing the

cathode in a five-zone furnace. Hydrogen, with a dew point of -55°C , flows through the five zones at a rate of 40 cubic feet per hour. In the first zone, the cathode is heated from room temperature to 750°C at $45^{\circ}\text{C}/\text{minute}$. In the second zone, the cathode is maintained at 750°C for 8 minutes. The third zone holds the cathode at 900°C for 16 minutes. Zone four maintains the temperature at 825°C for 8 minutes. The fifth zone cools the cathode to room temperature at $15^{\circ}\text{C}/\text{minute}$.

2. Elimination of Contaminants

It has long been known that the presence of electronegative molecules in the gas mixture (with the notable exception of the halogens) leads directly to the generation of after-pulses and therefore instability.³ Early efforts to improve upon the 6993 were concentrated in this area. The GM tube gas mixture which has been in use at Victoreen for many years has always been prepared with the utmost care to assure exceptional purity. Nonetheless, the possibility of some impurity always exists, so several steps were taken to reduce this possibility:

- a. Perform gas analysis
- b. Install additional filters in gas line
- c. Increase temperature at which tubes are evacuated
- d. Increase evacuation/bake time
- e. Improve vacuum system

Steps c, d, and e made the greatest improvement of any of these steps. Apparently the gas mixture, which is purchased on special order to very high

³Serge A. Korff, Geiger Counters -- Theory, Operation and Manufacture (New York, New York University, 1970), pp. 43-44.

purity standards, has been quite good, since the presence of electronegative contaminants is less than 10 parts per million. Thus, the filters made no improvement, and in fact, created more problems in that they tended to trap the halogen constituent, changing the mixture ratio. The most important factor relating to gas purity was the removal of every trace of air which had been inside the tube prior to evacuation.

The evacuation of a tube is more complex than simply connecting it to a good vacuum pump. The pump port must be as large as possible and the connecting tubing between the pump and the tube must have a large diameter. The vacuum gauge should be placed in a location which is about the same distance from the pump as the tubes are, with the connecting tubing the same diameter. Very serious errors in the estimate of the vacuum inside the tube will be made if these precautions are not followed.

By eliminating sharp bends and small diameter tubing on the exhaust manifold, substantial improvement can be achieved in the vacuum attained within the tube.

The high temperature bake during the evacuation process greatly increases outgassing on the tube's inner surfaces and improves pumping efficiency. By improving the construction of the tube so that it would stand higher temperatures, it was possible to raise the baking temperature and thus improve the vacuum in the tube.

3. Length/Diameter Ratio Improvement

The length to diameter ratio of the active portion of the 6993 is only 1.25:1, which is generally considered poor. Ideally, the ratio should be greater in order to reduce end effects.⁴

⁴Ibid., p. 35.

The change in starting voltage with time (shown in Figure 7) was found to be directly related to the build-up of charge on the insulators at the ends of the tube. When voltage is first applied, the insulators are uncharged, and the gradient between anode and cathode takes on a certain form. But due to the very high gradient, especially near the anode wire, the insulators begin to charge and eventually reach an equilibrium value. This charge affects the tube's operating parameters.

It was found that by waiting several hours with no voltage applied, the charge leaked off and the original conditions were restored. Also, by shining a very large Strontium-90 source through the beta window directly at the insulator surfaces, the charge could be made to dissipate immediately.

Clearly if the insulators could be moved farther apart, this effect would be reduced.

A number of attempts to prevent the charge build-up were tried, such as reducing the resistivity of the insulators, plating the surfaces to provide a rapid leakage path, and changing the insulator shape to reduce its effect on the gradient. All of these changes were unsatisfactory and introduced more problems. They were therefore not implemented.

Because there is some unused space inside the 6993 between the base and the lower insulator, it would be possible to move the lower insulator down closer to the base and thus increase the active length. This also, of course, increases the tube's sensitivity, which is not acceptable. But the improvement in L/D ratio is substantial. These conflicting problems were solved, as described in the next section, by increasing the insulator spacing and reducing the tube's counting efficiency in a manner which produced a dramatic result.

4. Cathode/Anode Diameter Ratio Improvement

The analysis of the 6993 anode pulse described earlier, and the apparent two-part plateau when operated into a low-impedance, indicated strongly that the quenching process within the tube was not complete but required assistance by the external circuit. Thus a tube which is really non-self-quenching, at least over part of its "plateau," was being asked to work into a circuit which demands an almost perfect internal quenching process.

Studies by Van Zoonen⁵ have shown that a rare-gas-halogen GM tube behaves in the "classical" manner (i. e., similar to an organically-quenched tube) only in a certain region of the plateau from the starting voltage, V_s , up to a transition voltage, V_t . V_t is the point at which the "double pulses" shown in Figure 10 start to appear.

These studies also show that below V_t , the charge per pulse is independent of the series resistance, R_s , and the shunt capacitance, C_p , but above V_t , the charge per pulse is dependent upon these two parameters such that the greater C_p , or the smaller R_s , the greater is the charge per pulse. Once the transition region is entered, the length of the upper portion of the plateau is dependent upon C_p and R_s since they affect the charge per pulse and thus the chances for after-discharges.

Van Zoonen also describes the effect of the cathode/anode diameter ratio on $V_t - V_s$. If the field at the cathode can be kept below a certain critical value, F_c , the transition region will not be reached. The classical expression for the field at any point in a cylindrical tube, and in this case the field at the cathode

⁵D. van Zoonen, "Double Pulses in Rare Gas-Halogen Geiger Counters, "Appl. Sci. Res., B5 (1956), pp. 368-386.

$$F_b = \frac{V}{b \ln (b/a)}$$

where

V = anode voltage

a = anode radius

b = cathode radius

shows the relationship between these parameters.

In designing the D-103 tube, it was felt that the best design approach would be the most conservative one; i.e., to pursue a design in which V_t is not traversed even though in practice it is possible to use tubes in low impedance circuits which operate in the transition region. While this clearly will not ensure that the tube will be good, it is a good design goal because the charge per pulse will be kept low, and independent of the external circuit, minimizing the chance for after-pulses.

The elimination of the "distorted" current pulses above a certain voltage was thus seen to be the most important goal to pursue. These "double pulses" consist of a first portion which looks like the single pulse observed below the transition voltage, and a second portion which occurs following the first pulse. Because of the ORNL circuit dead time, these pulses themselves cannot be counted as two pulses by the circuit. However, the second portion of the pulse is non-self-quenching; in fact the multiplication in the pulse continues until the potential in the tube drops to about the starting voltage, V_s .⁶ Thus an external series resistance, with associated low shunt capacitance, will allow the tube's potential to drop and the discharge to be quenched. The ORNL circuit will not.

⁶ Ibid.

In certain types of commercial rare-gas-halogen tubes, the double-pulse region occupies practically the entire plateau. While these tubes are often called "halogen-quenched," they are really non-self-quenching because of their requirement for a large series resistance and low shunt capacitance which aid the quenching process substantially. These tubes are always characterized by a cathode to anode diameter ratio which is quite small compared with the classical self-quenching alcohol-argon GM tubes. Truly self-quenching halogen GM tubes always have relatively fine anodes, so that the cathode to anode diameter ratio is large.

An increase in the cathode diameter, or a reduction in the anode diameter would produce the desired effect in the 6993. Clearly, no increase in cathode diameter is possible because of size limitations. Thus the anode diameter was reduced from the 0.022 inch which had been in use to a 0.007 inch diameter, after many trials of various sizes. This simple geometric change made two major changes in the tube's operation.

- a. The length of the single-pulse region of the plateau was increased from about 40 volts to over 130 volts in the ORNL circuit.
- b. The "active volume" of the tube was reduced because the region near the cathode no longer has sufficient gradient to sustain an avalanche. This reduces the tube's efficiency to gamma radiation, making it possible to increase the length-to-diameter ratio and thus reduce end effects. Another advantage of the lower gradient near the cathode is the greatly reduced possibility of secondary emission from the cathode wall initiating an after-pulse.

5. Individual Filling for Centering of Plateau

In spite of all the precautions which may be taken to ensure GM tube uniformity, it has been found that the only way to produce large numbers of good-quality tubes is to give each one individual attention. After all of the improvements mentioned above were implemented, a method was devised to check the important operating parameters of each tube while it is being filled with gas, but before it is sealed, or "tipped-off."

A circuit, consisting of the elements described in Figure 9, is connected individually to each GM tube on the exhaust stand after it has been baked and evacuated, but before it is backfilled. A voltage of 1030 volts is applied to the tube and the gas mixture is slowly allowed to enter the tube. The oscilloscope trace is carefully observed. At first, serious double-pulsing is observed indicating a non-self-quenching condition. When the correct pressure has been achieved, the double-pulsing will just disappear, so that only single pulses occur. The top of the self-quenching plateau is now adjusted to exactly 1030 volts. This is a safety margin of 40 volts above the required 990.

Next the voltage is reduced to 835 volts, 25 volts below the minimum 860-volt starting voltage requirement. In most cases, the tube will trigger the counting circuit, indicating that it has a plateau length, totally in the self-quenching region, which is considerably longer than the specification requirement. In some cases, the tube will not trigger the counting circuit. Then, a small amount of gas is removed, very slowly, until the circuit triggers. With this new pressure held in the tube, the voltage is increased to 1010 volts to observe the pulse shape. This is 20 volts above the maximum operating voltage, still allowing plenty of safety margin. If double-pulsing is observed, the tube is considered to be defective and is rejected.

In order to obtain the exact gas pressure for each tube, it is necessary to "juggle" the pressure up and down, checking for starting voltage and transition voltage several times. The procedure is painstaking, time-consuming and must be performed by a skilled operator, but results in a very good yield. This is actually a form of quality control within the manufacturing process, and is much preferable to the industry practice of filling all tubes to a fixed pressure and then checking them after it is too late to do anything to them.

The average filling pressure of the gas mixture in the D-103 is 600 mm Hg. The gas mixture was modified somewhat from the Victoreen standard mixture to allow better control using the plateau centering procedure, and consists of neon with carefully controlled trace amounts of argon and chlorine. The mixture ratio is quite critical.

Performance of D-103

Tests similar to those performed on the 6993's were run for the experimental D-103 tubes. Sample curves are shown in Figures 11 through 15.

The curves clearly show the vast superiority of the new D-103 design over the earlier tubes. Specifically, compared with the 6993, the tubes exhibit:

1. Long plateau -- typically greater than 200 volts into the low-impedance test circuit, well in excess of the 130 volts required by the specification.
2. Less shift in starting voltage -- about 15 volts typical.
3. Short term stability better than $\pm 5\%$ -- typically unmeasurable on the charts.
4. Flat Plateau
5. Small hysteresis effect
6. No difference in plateau length or slope between 5 mR/h and 50 mR/h measurements.

Tests performed at Victoreen as well as at the OCD/STRATCOM Instrumentation Test Facility on production lots of tubes indicate conformance with the comprehensive D-103 specification. As of this writing, 4000 tubes have been supplied to OCD, and all have been accepted. Two complaints voiced by the testing facility on certain tubes were:

1. The tube base was not aligned perfectly with the tube, so that the pins come out at a slight angle. This was corrected simply by making sure that the bases were put on straight.
2. During temperature tests, when some tubes were returned to room temperature from -50°F , water condensed onto the outer insulator surface around the anode lead causing a leakage path and erratic per-

formance until the water evaporated. This was corrected by improving the epoxy seal between the base and the tube body.

Both of these difficulties are, of course, extremely minor when compared with the original OCD GM tubes.

Because the ORNL circuit is designed to simulate worst-case CD V-700 performance, the D-103 will probably perform even better in some of the instruments in the field. For example, the CD V-700 built by Electro-Neutronics, Inc., has an input impedance which is much higher than the 4000 ohms of the ORNL circuit and a discrimination level much lower than the ORNL one-half volt, although its high voltage power supply is poorly regulated. Tests indicate that operation in these instruments as much as 50 to 100 volts below the specified minimum operating voltage of 860 volts is quite feasible. Thus it may be possible to retrofit some of the ENI instruments having very low probe voltages with the new D-103, without any further modifications whatsoever.

The complete elimination of pulse distortion, or "double pulses," throughout the operating range has virtually eliminated the problem of distorted pulses being counted as more than one pulse. Thus the combination of short instrument dead time and low discrimination level which occurs in some instruments, and which has been referred to by ORNL as a potential problem,⁷ should no longer be troublesome.

The stability of the D-103 is vastly improved for several reasons.

1. The length to diameter ratio reduces end effects dramatically.
2. The improved cathode cleaning and processing technique reduces the

⁷J. M. Rochelle, Review and Evaluation of the OCD-D-103 GM Tube Specification Testing Procedure (Oak Ridge, Tennessee, Oak Ridge National Laboratory, 1969), pp. 18-23.

amount of contamination within the tube which can lead to after-pulses, and the non-porous surface minimizes halogen adsorption.

3. The carefully controlled gas purity minimizes after-pulses.
4. The absence of double pulses minimizes after-pulses.
5. The flat plateau minimizes the effects of any slight changes which might occur in the position of the plateau with respect to voltage or other parameters.

The effects of "jamming" have been greatly reduced with the new D-103 design. Jamming is an apparent reduction in count rate with increasing radiation exposure rate caused by reduced pulse height. At very high counting rates, most GM pulses have abnormally low amplitude such that some or even all of them may not trigger the external counting circuit. This can result in a zero reading on a survey meter with high exposure rates.

The CD V-700 circuit makes no provision for anti-jamming. It is therefore necessary that the GM tube be designed so that at a specified counting rate, a sufficient percentage of the pulses will have enough amplitude to trigger the circuit at the lowest operating potential to drive the meter off scale. It should be pointed out that, with a circuit of this type, some counting rate can always be achieved above which the pulses are too small to trigger the circuit and the meter will read zero.

In the design of the D-103 tube, the counting rate that causes jamming was increased by assuring that the plateau was longer than that required at low counting rates.

If the starting voltage is considerably below the lowest operating voltage, jamming becomes less of a problem.

Fortunately, the plateau of the D-103 is, in most tubes, considerably longer than the minimum allowed by the specification requirement. Because of the individual plateau adjustment technique used in the filling of each tube, most tubes exceed the jamming requirement by a very wide margin.

The improved hysteresis effect is also due to the reduction of the after-pulsing problem and the virtual elimination of contaminants. Thus the tube is able to withstand very high exposure rates for long periods of time, even with high anode potentials, without any significant short or long term damage.

In all important respects, the D-103 performance in the ORNL circuit, and therefore in the CD V-700, is substantially better than the 6993, and performs even better than the "hypothetical" tube called for in the D-103 specification.

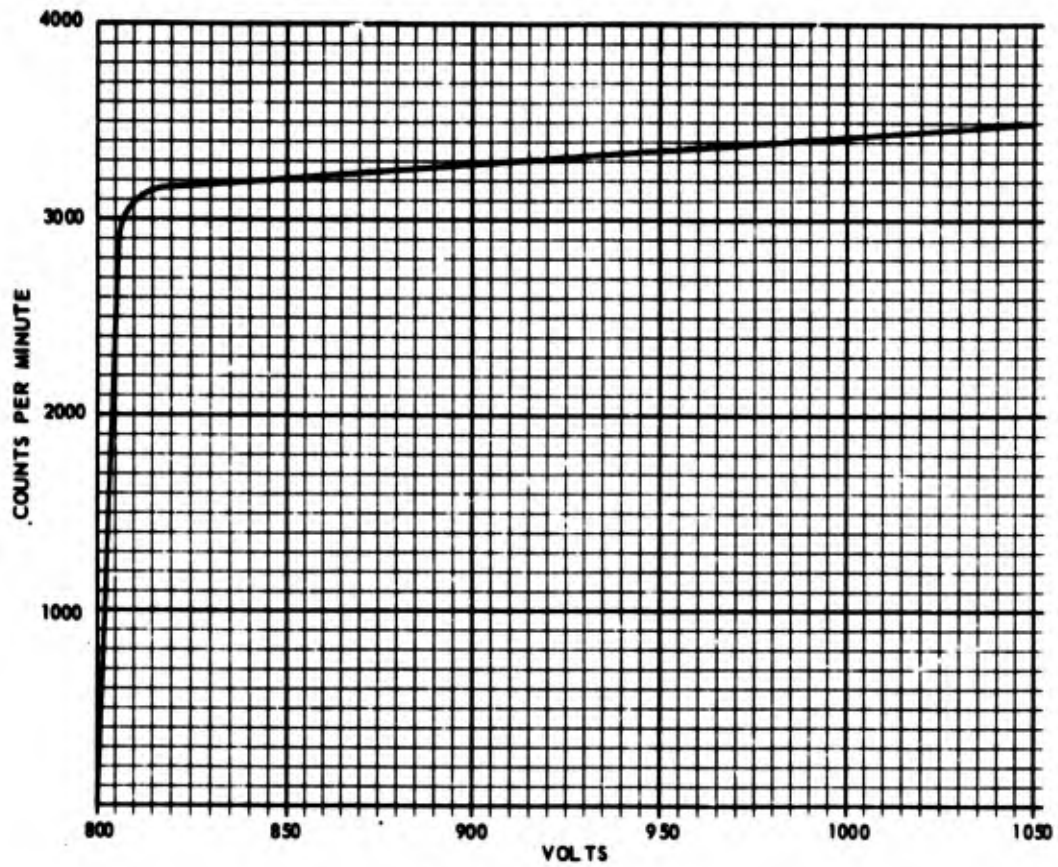


Figure 11. D-103 Plateau Curve with ORNL Circuit. 5 mR/h
No Prior Tests For Several Hours

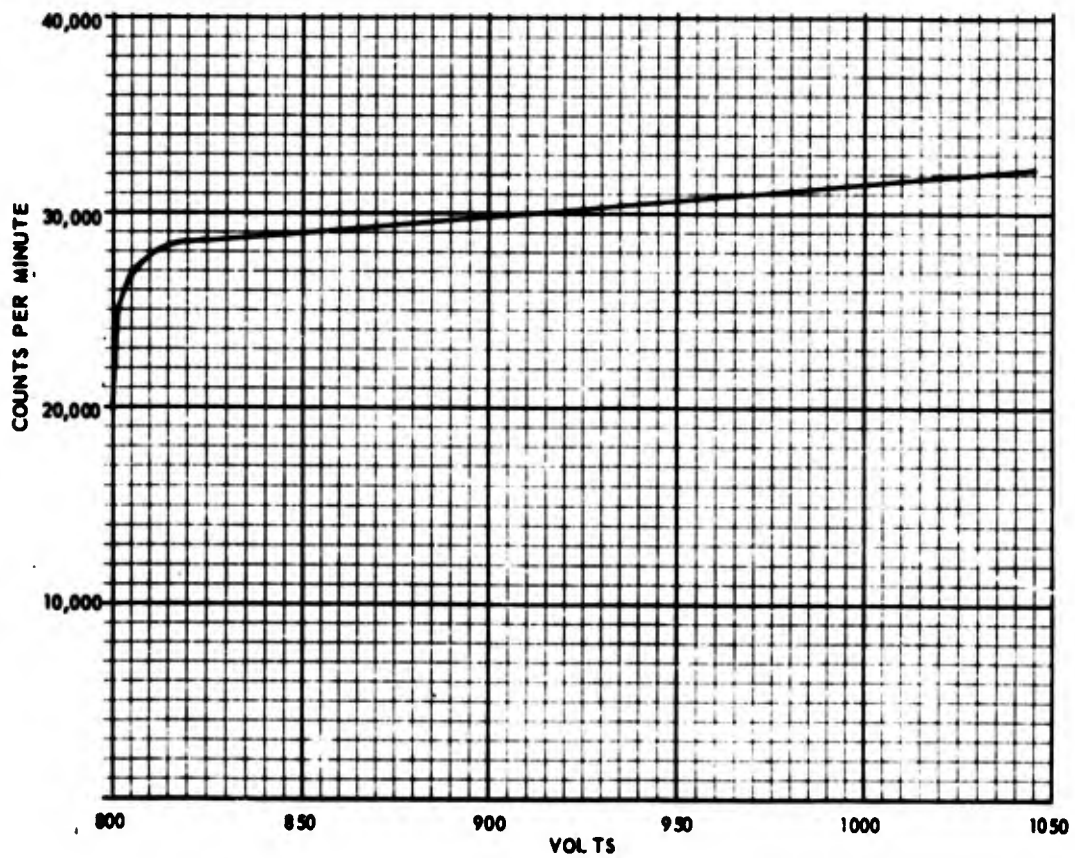


Figure 12. D-103 Plateau Curve with ORNL Circuit. 50 mR/h
Immediately Following 5 mR/h Test

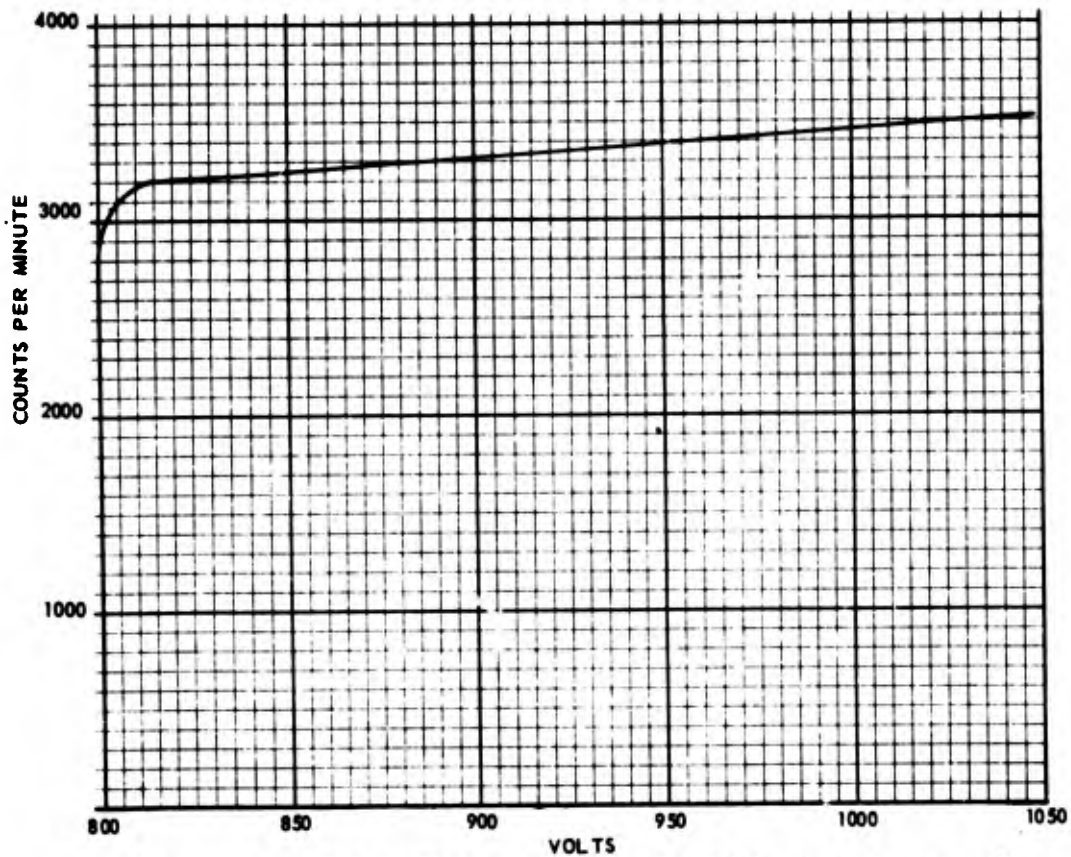


Figure 13. D-103 Plateau Curve with ORNL Circuit. 5 mR/h Immediately Following 50 mR/h Test

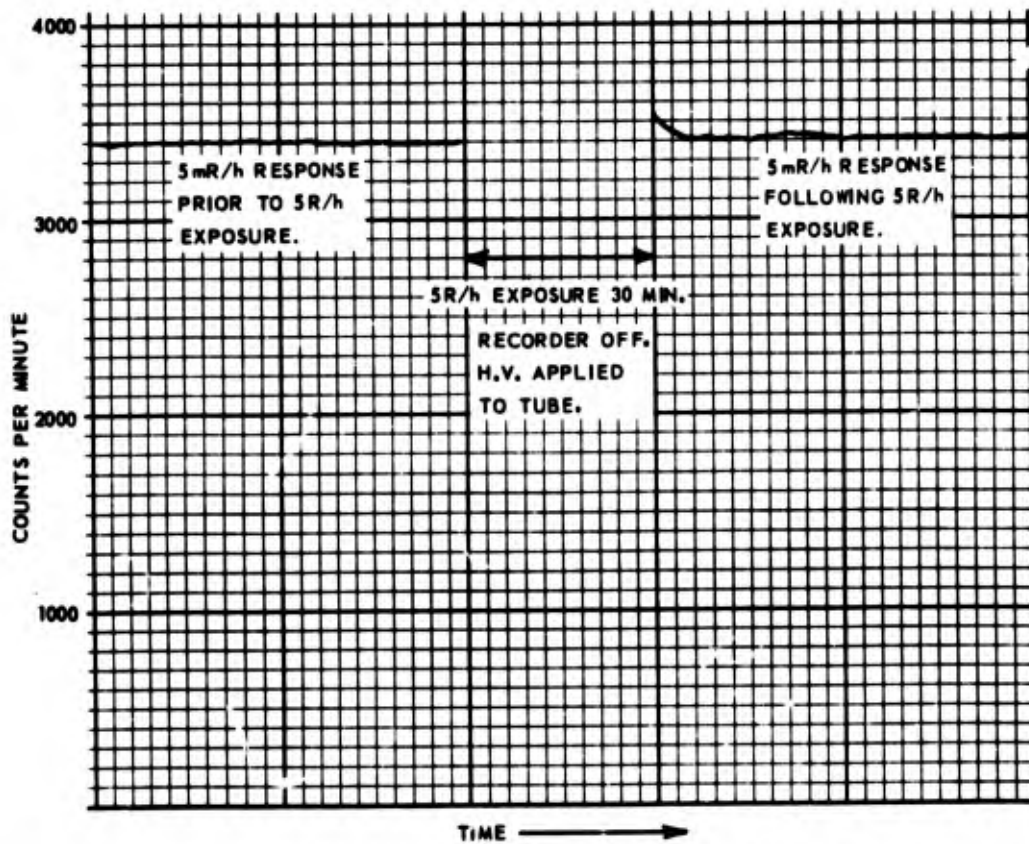


Figure 14. Hysteresis Test -- D-103 with ORNL Circuit

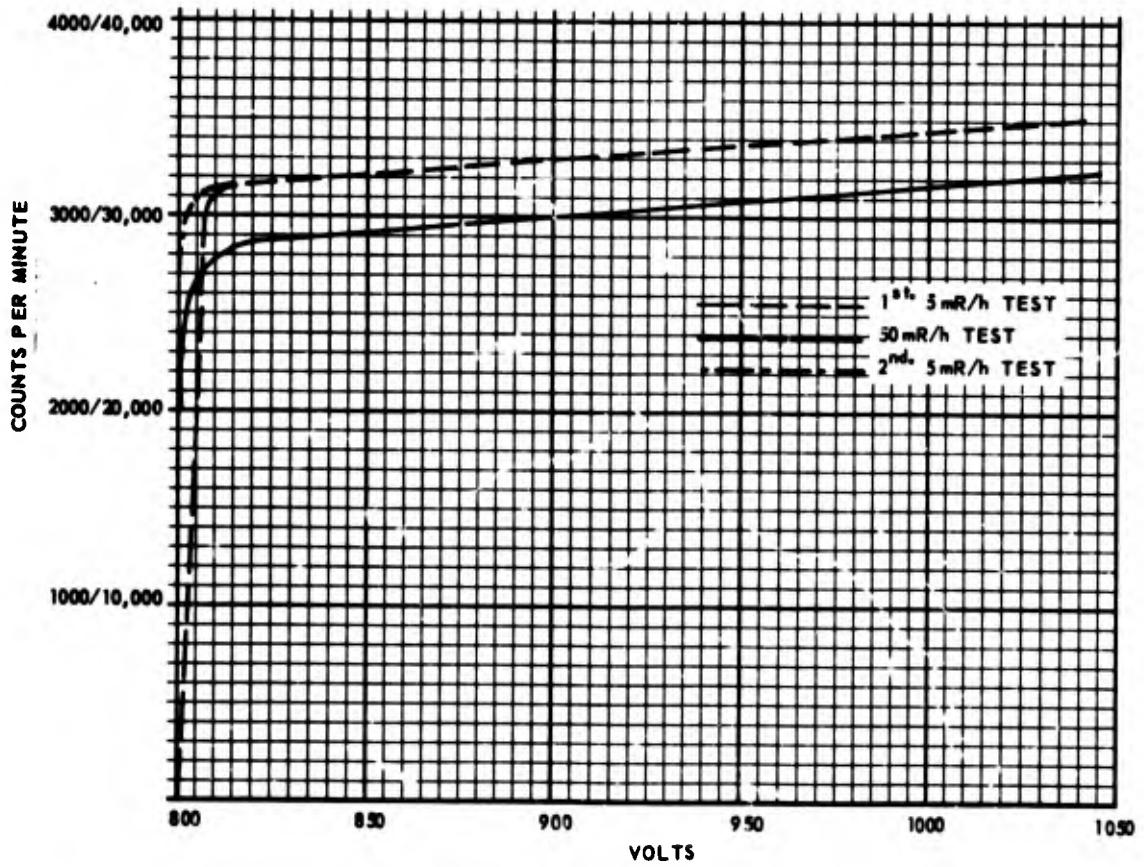


Figure 15. D-103 Plateau Curve Composite.

D-103 Mechanical Construction

A photograph of the OCD-D-103 developed by Victoreen, is shown in Figure 16.

Figure 17 is a cutaway view of the OCD-D-103. The drawing is to scale, and is shown twice actual size. The composition of all the materials used in the construction of the tube is listed.



Figure 16. OCD-D-103 GM Tube

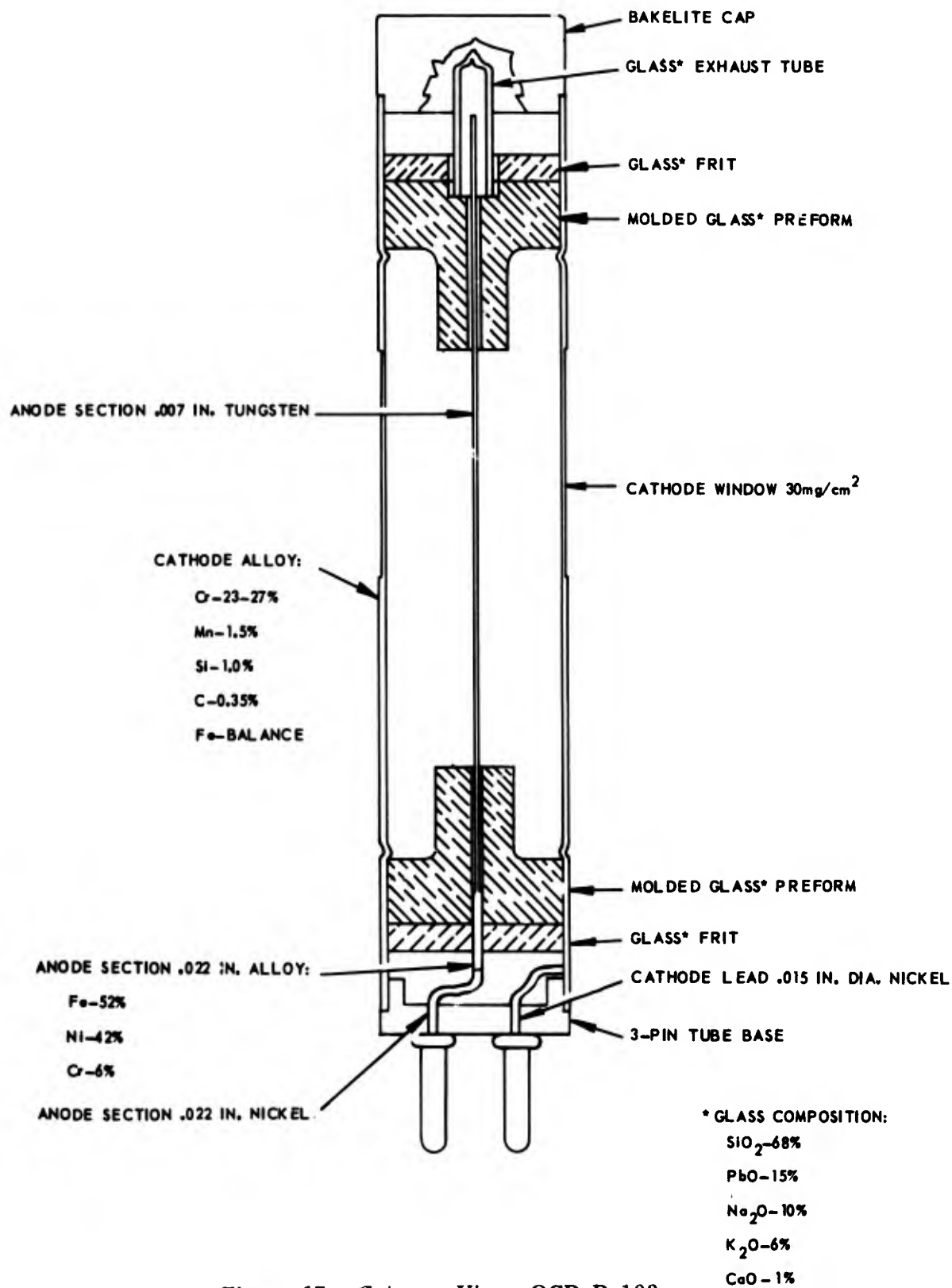


Figure 17. Cutaway View, OCD-D-103

Conclusion

The OCD-D-103 GM Tube is vastly superior to the 6993 in all important respects, especially when the two are compared in a low-impedance circuit such as the CD V-700 or the ORNL Interface. It exceeds the performance requirements of the OCD-D-103 specification, most notably in its plateau length and slope. When measured in a conventional high impedance circuit, the plateau length is even longer.

It is expected that the OCD-D-103 will improve markedly the performance and reliability of the CD V-700, and any other survey meter in which it might be used.

BIBLIOGRAPHY

1. American National Standard and IEEE Standard Test Procedure for Geiger-Muller Counters, New York, Institute of Electrical and Electronics Engineers, 1969.
2. Clark, L. B., Sr., Recent Developments in the Production of Halogen Quenched Geiger-Muller Counting Tubes, Washington, Naval Research Laboratory.
3. _____, and T. D. Hanscome, Chlorine Quenched Geiger Muller Tubes for High Temperature Application, Washington, Naval Research Laboratory.
4. Friedman, Herbert, "Geiger Counter Tubes," Proceedings of the I. R. E., Vol. 37, No. 7 (July, 1949), pp. 791-808.
5. Korff, Serge A., Geiger Counters -- Theory, Operation and Manufacture, New York, New York University, 1970.
6. Managan, William W., Design of a G-M Counter Tube for High Counting Rates, Cleveland, The Victoreen Instrument Co., 1949.
7. Rochelle, J. M., Review and Evaluation of the OCD-D-103 G-M Tube Specification Testing Procedure, Oak Ridge, Tennessee, Oak Ridge National Laboratory, 1969.
8. Srdoc, D., "Gas Discharge Mechanism and Properties of Halogen-Quenched Counters," Nuclear Instruments and Methods, 99 (1972), pp. 321-332.
9. Wilson, H. N., Oak Ridge National Laboratory, private communication.
10. Zoonen, D. van, "Delay in the Build-up of Halogen-Quenched Counters," Appl. Sci. Res., B3 (1953), pp. 377-389.
11. _____, "Double Pulses in Rare Gas-Halogen Geiger Counters," Appl. Sci. Res., B5 (1956), pp. 368-386.
12. _____, "Gas Discharge Mechanism of Halogen-Quenched Counters," Appl. Sci. Res., B4 (1955), pp. 237-248.

APPENDIX

Final OCD-D-103 Specification

DEPARTMENT OF THE ARMY
OFFICE OF CIVIL DEFENSE

STANDARD ITEM SPECIFICATION

AUGUST 24, 1971

ITEM No. OCD-D-103

NOMENCLATURE: GEIGER-MUELLER TUBE
BETA-GAMMA DISCRIMINATING

1. SCOPE

THIS SPECIFICATION CONTAINS THE DETAIL REQUIREMENTS FOR A GEIGER-MUELLER TUBE WHICH WILL BE USED ONLY WITH THE INSTRUMENTS LISTED BELOW AND MUST BE ELECTRICALLY AND MECHANICALLY COMPATIBLE WITH THESE INSTRUMENTS. THE TUBE SHALL BE A BETA-GAMMA DETECTION AND DISCRIMINATION TYPE, SIMILAR TO THE OCD ITEM 6993.

CDV-700	ANTON MODEL 5
CDV-700	ANTON MODEL 6
CDV-700	VICTOREEN MODEL 6
CDV-700	VICTOREEN MODEL 6A
CDV-700	VICTOREEN MODEL 6B
CDV-700	LIONEL MODEL 6B
CDV-700	ELECTRO-NEUTRONICS MODEL 6B
CDV-457	DEMONSTRATION UNIT (ALL MODELS)

2. APPLICABLE DOCUMENTS

FEDERAL SPECIFICATIONS PPP-B-636, MILITARY SPECIFICATIONS MIL-S-901, MIL-STD-105, MIL-STD-202 AND MIL-D-70327, ATTACHMENT A - GM TUBE SPECIFICATION, ATTACHMENT B - PROBE ASSEMBLY, ATTACHMENT C - OSCILLOSCOPE TRACE; AND ORNL Q-2903B-0 WHICH IS INCLUDED WITH THIS DOCUMENT.

3. REQUIREMENTS

3.1 SAMPLES.

3.1.1 PREPRODUCTION SAMPLES. THE CONTRACTOR SHALL SUBMIT TEN (10) SAMPLES OF THE ITEM TO BE SUPPLIED FOR TESTING AND INSPECTION BY THE GOVERNMENT IN ACCORDANCE WITH PARAGRAPH 4.5. FIVE (5) OF THE SAMPLES SHALL BECOME THE PROPERTY OF THE GOVERNMENT AND FIVE (5) SAMPLES SHALL BE RETURNED TO THE CONTRACTOR.

3.1.2 INITIAL PRODUCTION SAMPLES. PRIOR TO BEGINNING PRODUCTION, AN INITIAL PRODUCTION RUN OF 300 SAMPLES OF THE ITEM SHALL BE SUPPLIED FOR APPROVAL AND INSPECTION AT THE CONTRACTOR'S FACILITIES IN ACCORDANCE WITH PARAGRAPH 4.6. AT LEAST TWENTY (20) SAMPLES SHALL BE SELECTED FOR TESTS AND INSPECTION AND FIVE (5) OF THE APPROVED SAMPLES SHALL BECOME THE PROPERTY OF THE GOVERNMENT, THE BALANCE SHALL BE RETURNED TO THE CONTRACTOR.

3.2 GENERAL REQUIREMENTS. THE GEIGER-MUELLER TUBE SHALL BE A BETA-GAMMA, HIGH SENSITIVITY TUBE WHICH WILL MEASURE GAMMA EXPOSURE RATES TO 50 MR/HR. THE TUBE SHALL BE DESIGNED FOR CONTINUOUS USE IN EXCESS OF 500 HOURS AND SHALL HAVE SUFFICIENT DURABILITY TO WITHSTAND THE NORMAL OPERATIONAL AND STORAGE ENVIRONMENT. THE DESIGN SHELF-LIFE FOR THE TUBE SHALL BE FOR AT LEAST TEN YEARS. THE TUBE SHALL BE HALOGEN SELF-QUENCHING AND DESIGNED FOR OPERATION IN THE INSTRUMENTS OF PARAGRAPH 1 OVER THE RANGE FROM 860 VOLTS TO 990 VOLTS.

3.3 PERFORMANCE CHARACTERISTICS.

3.3.1 ABSOLUTE RATINGS. THE TUBE SHALL HAVE THE FOLLOWING RATINGS AS TABULATED BELOW:

MINIMUM OPERATING VOLTAGE RANGE	860 VOLTS TO 990 VOLTS
MINIMUM OPERATING TEMPERATURE RANGE	- 10°F TO +130°F
ALTITUDE, ABOVE SEA LEVEL	20,000 FT.

3.3.2 BACKGROUND AND CONTAMINATION. THE MAXIMUM ALLOWABLE COUNT RATE AT AN OPERATING VOLTAGE OF 990 VOLTS SHALL BE 40 COUNTS PER MINUTE. THE TUBE SHALL BE OF A CONSTRUCTION SUCH THAT THE ACTIVE GAS VOLUME IS OPAQUE TO VISIBLE LIGHT.

3.3.3 EFFECTIVE DEAD TIME. THE DEAD TIME OF THE TUBE SHALL NOT EXCEED 200 MICROSECONDS IN A UNIFORM Cs^{137} GAMMA RADIATION FIELD OF 500 MR/HR.

3.3.4 SHORT TERM STABILITY. AFTER THE TUBE HAS BEEN OPERATING AT 925 VOLTS IN A UNIFORM GAMMA RADIATION FIELD OF 50 MR/HR. FOR A PERIOD OF ONE HOUR AFTER THE INITIAL APPLICATION OF HIGH VOLTAGE TO THE TUBE, THE COUNT RATE SHALL EQUAL THE INITIAL COUNT RATE $\pm 5\%$.

3.4 ACCURACY OF COUNT RATE RESPONSE. THE TUBE SHALL GIVE THE FOLLOWING COUNT RATE RESPONSE TO THE CALIBRATED Cs^{137} UNIFORM GAMMA RADIATION INTENSITIES SPECIFIED WITHIN THE TOLERANCES SPECIFIED WHEN OPERATING AT THE VOLTAGES SPECIFIED:

<u>GAMMA FIELD</u>	<u>VOLTAGE</u>	<u>COUNT RATE RESPONSE</u>	<u>TOLERANCE</u>
5 MR/HR	925 VOLTS	2700-1700 COUNTS/MIN	
5 MR/HR	860 VOLTS	5 MR/HR, 925 VOLT RESPONSE	+3% AND -18%
5 MR/HR	990 VOLTS	5 MR/HR, 925 VOLT RESPONSE	+18% AND -3%
50 MR/HR	925 VOLTS	5 MR/HR, 925 VOLT RESPONSE TIMES 10	+1% AND -15%
50 MR/HR	860 VOLTS	50 MR/HR, 925 VOLT RESPONSE	+3% AND -18%
50 MR/HR	990 VOLTS	50 MR/HR, 925 VOLT RESPONSE	+18% AND -3%

IF THE TUBE FAILS TO MEET THE REQUIREMENTS OF THE TEST ON THE FIRST MEASUREMENT, A SECOND MEASUREMENT SHALL BE TAKEN. THE RESULTS OF THE FIRST MEASUREMENT SHALL BE DELETED AND THE RESULTS OF THE SECOND MEASUREMENT SUBSTITUTED. ONE AND ONLY ONE SUCH SUBSTITUTION SHALL BE ALLOWED FOR EACH READING.

3.5 HYSTERESIS AND RADIATION DAMAGE. THE TUBE SHALL BE EXPOSED TO A ^{137}Cs GAMMA RADIATION FIELD OF 50 MR/HR AND THE COUNT RATE MEASURED. THE TUBE SHALL THEN BE EXPOSED TO A 5 R/HR FIELD FOR A PERIOD OF 30 MINUTES. WITHIN ONE MINUTE AFTER REMOVAL OF THE 5 R/HR FIELD, THE COUNT RATE IN A 50 MR/HR FIELD SHALL BE A MINIMUM OF MINUS 30% OF THE INITIAL COUNT RATE. FIVE MINUTES AFTER REMOVAL OF THE 5 R/HR FIELD, THE COUNT RATE SHALL EQUAL THE INITIAL COUNT RATE $\pm 10\%$. OPERATING VOLTAGE SHALL BE 990 VOLTS THROUGHOUT THE TEST.

3.6 JAMMING. OPERATING AT 860 VOLTS, THE TUBE SHALL RETAIN A COUNT RATE WHICH EQUALS OR EXCEEDS THE COUNT RATE IN A 50 MR/HR ^{137}Cs GAMMA RADIATION FIELD WHEN OPERATED AT 860 VOLTS IN A 1.0 R/HR ^{137}Cs GAMMA RADIATION FIELD FOR A PERIOD OF 30 MINUTES.

3.7 TEMPERATURE OPERATION. THE COUNTING RATE OF THE TUBE OPERATED IN A GAMMA RADIATION FIELD AT TEMPERATURE EXTREMES FROM -10°F TO $+130^{\circ}\text{F}$ SHALL BE WITHIN $\pm 5\%$ OF THE COUNT RATE AT ROOM TEMPERATURE.

3.8 TEMPERATURE STORAGE. THE TUBE SHALL BE CAPABLE OF WITHSTANDING STORAGE AT -50°F AND $+160^{\circ}\text{F}$ AND SHALL MEET THE REQUIREMENTS OF THIS SPECIFICATION AFTER SUCH STORAGE.

3.9 SHOCK AND VIBRATION. THE TUBES SHALL BE OF RUGGEDIZED DESIGN AND SHALL MEET THE TESTS OF 4.6.9 AND 4.6.10.

3.10 OPERATING LIFE. THE TUBE SHALL BE DESIGNED TO OPERATE CONTINUOUSLY AT 990 VOLTS FOR 500 HOURS IN A GAMMA RADIATION FIELD OF 1MR/HR.

3.11 PRESSURE OPERATION. THE TUBE SHALL BE DESIGNED TO OPERATE AT AN ALTITUDE OF 20,000 FEET ABOVE SEA LEVEL WITHIN AN ACCURACY OF $\pm 5\%$ OF THE SEA LEVEL COUNT RATE RESPONSE.

3.12 MARKING AND IDENTIFICATION. EACH TUBE SHALL BE MARKED WITH "OCD-D-103", THE MANUFACTURER'S NAME OR SYMBOL, AND THE MONTH AND YEAR OF MANUFACTURE AS INSTRUCTED BY OCD. THE METHOD AND TYPE OF MARKING SHALL BE APPROVED BY THE CONTRACTING OFFICER PRIOR TO SUBMISSION OF THE INITIAL PRODUCTION SAMPLES.

3.13 CONSTRUCTION AND SIZE.

3.13.1 THE TUBE SHALL BE CONSTRUCTED TO MEET THE DIMENSIONAL REQUIREMENTS OF (ATTACHMENT A) AND SHALL FIT IN THE STANDARD OCD GM TUBE PROB. (ATTACHMENT B.)

3.13.2 BETA RESPONSE. THE TUBE SHALL HAVE A BETA WINDOW $3/4$ INCH LONG EXTENDING COMPLETELY AROUND THE PERIPHERY OF THE TUBE. THIS WINDOW SHALL HAVE A MAXIMUM DENSITY OF 30 MILLIGRAMS PER SQUARE CENTIMETER AND SHALL NOT ATTENUATE THE BETA EMITTED BY Bi^{210} (RADIUM E) BY MORE THAN 10% REGARDLESS OF THE DIRECTION OF IRRADIATION PARALLEL TO THE TUBE DIAMETER.

3.13.3 CONNECTOR. THE CONNECTOR SHALL BE A STANDARD PEE-WEE 3-PIN BASE. ALL PINS SHALL BE 0.47 INCHES LONG NOMINAL, AND 0.093 INCHES IN DIAMETER.

3.14 PRODUCTION DRAWINGS. ONE COPY AND A REPRODUCIBLE TRANSPARENCY OF THE ENGINEERING DRAWINGS AND SPECIFICATIONS FOR MANUFACTURE OF THE TUBE SHALL BE SUPPLIED IN ACCORDANCE WITH MIL-D-70327. THE DRAWINGS SHALL BE APPROVED BY THE CONTRACTING OFFICER.

3.15 CHANGES. THE CONTRACTOR SHALL OBTAIN WRITTEN APPROVAL FROM THE CONTRACTING OFFICER PRIOR TO MAKING ANY CHANGES FROM THE APPROVED PREPRODUCTION OR INITIAL PRODUCTION SAMPLES PRODUCED UNDER THE REQUIREMENTS OF THIS SPECIFICATION.

3.16 CONFLICTS. IN THE EVENT THERE ARE CONFLICTS BETWEEN THE DRAWINGS (ATTACHMENTS A AND B) AND THE WRITTEN SPECIFICATION OR BETWEEN THE APPLICABLE DOCUMENTS AND THE WRITTEN SPECIFICATION, THE WRITTEN SPECIFICATION SHALL GOVERN.

3.17 WORKMANSHIP. THE STANDARDS OF WORKMANSHIP SHALL CONFORM TO REQUIREMENT 9 OF MIL-STD-454.

4. TESTING AND INSPECTION

4.1 CONTRACTOR'S RESPONSIBILITY FOR INSPECTION. UNLESS OTHERWISE SPECIFIED IN THE CONTRACT OR PURCHASE ORDER, THE CONTRACTOR IS RESPONSIBLE FOR PERFORMANCE OF ALL INSPECTION REQUIREMENTS AS SPECIFIED HEREIN. EXCEPT AS OTHERWISE SPECIFIED, THE CONTRACTOR MAY UTILIZE HIS OWN FACILITIES OR ANY COMMERCIAL LABORATORY ACCEPTABLE TO THE CONTRACTING OFFICER. THE GOVERNMENT RESERVES THE RIGHT TO PERFORM ANY OR ALL OF THE INSPECTIONS SET FORTH IN THESE SPECIFICATIONS WHERE SUCH INSPECTIONS ARE DEEMED NECESSARY TO ASSURE THAT SUPPLIES AND SERVICES CONFORM TO THE PRESCRIBED REQUIREMENTS.

4.2 INSPECTION OF MATERIALS AND COMPONENTS. IN ACCORDANCE WITH PARAGRAPH 4.1 ABOVE, THE CONTRACTOR IS RESPONSIBLE FOR INSURING THAT MATERIALS AND COMPONENTS USED IN THE END ITEM WERE MANUFACTURED, TESTED, AND INSPECTED IN ACCORDANCE WITH THE REQUIREMENTS OF THE REFERENCED SUBSIDIARY SPECIFICATIONS AND STANDARDS TO THE EXTENT SPECIFIED, OR IF NONE, IN ACCORDANCE WITH THIS SPECIFICATION. IN THE EVENT OF CONFLICT, THIS SPECIFICATIONS SHALL GOVERN.

4.3 GENERAL TESTING AND INSPECTION. THE INSPECTION AND TESTING OF THE ITEMS SHALL BE COMPRISED OF THE FOLLOWING CLASSIFICATIONS AS SPECIFIED HEREIN:

- (A) PREPRODUCTION INSPECTION
- (B) INITIAL PRODUCTION INSPECTION
- (C) PRODUCTION INSPECTION

SAMPLING FOR INSPECTION SHALL BE PERFORMED IN ACCORDANCE WITH MIL-STD-105 EXCEPT WHERE OTHERWISE INDICATED.

4.4 TEST CONDITIONS AND REQUIREMENTS. ALL TESTS TO BE PERFORMED UNDER THIS SPECIFICATION SHALL BE PERFORMED AS SPECIFIED HEREIN. THE TEST CONDITIONS AND CIRCUIT SPECIFIED BELOW SHALL BE USED.

4.4.1 TEST VOLTAGE. UNLESS OTHERWISE STATED, ALL TESTS SHALL BE PERFORMED AT 925 VOLTS.

4.4.2 TEST CIRCUIT. THE SPECIAL TEST CIRCUIT DESCRIBED IN TUBE TEST MODULE, FABRICATION SPECIFICATION Q-2903B-0 SHALL BE USED IN ALL TESTS TO ENSURE A CONTROLLED INPUT IMPEDANCE AND PULSE AMPLITUDE DISCRIMINATION LEVEL. THIS CIRCUIT FEATURES A TUBE SOCKET CONNECTED TO A CAPTIVE CABLE. THE GM TUBE UNDER TEST SHALL ALWAYS BE INSERTED IN THIS SOCKET AND UNDER NO CONDITIONS SHALL ANY OTHER ITEMS SUCH AS COMPONENTS, CABLES, ETC., BE USED BETWEEN THIS SOCKET AND THE TUBE UNDER TEST. THIS SPECIAL TEST CIRCUIT SHALL NOT BE CHANGED WITHOUT WRITTEN APPROVAL OF THE CONTRACTING OFFICER. THE SPECIAL TEST CIRCUIT FEATURES AN INPUT CONNECTOR FOR DIRECT CONNECTION TO A HIGH VOLTAGE POWER SUPPLY AND AN OUTPUT CONNECTOR FOR DIRECT CONNECTION TO A SCALER OR AN OSCILLOSCOPE. THE OUTPUT PULSE HAS A NOMINAL -10 VOLTS PULSE HEIGHT AND APPROXIMATELY 5 MICROSECONDS DURATION. THE SCALER TO BE USED IN CONJUNCTION WITH THIS TEST CIRCUIT SHALL HAVE AN INPUT IMPEDANCE GREATER THAN 1000 OHMS, SHALL HAVE A RESOLVING TIME LESS THAN 10 MICROSECONDS, AND SHALL HAVE A DISCRIMINATOR WHICH IS SET TO NEGATIVE FIVE VOLTS REFERRED TO THE SCALER INPUT. THE OSCILLOSCOPE TO BE USED IN CONJUNCTION WITH THE SPECIAL TEST CIRCUIT SHALL HAVE A CRT DISPLAY OF AT LEAST 10 CENTIMETERS HORIZONTAL AND 4 CENTIMETERS VERTICAL. IT SHALL HAVE AN INPUT IMPEDANCE GREATER THAN 1000 OHMS, A -3 DB BANDWIDTH GREATER THAN 1 MEGAHERTZ, THE CAPABILITY OF HORIZONTAL SWEEP RATES OF UP TO 1 MICROSECOND PER CENTIMETER, AND THE CAPABILITY OF INTERNAL NEGATIVE SLOPE TRIGGERING. THE HIGH VOLTAGE POWER SUPPLY TO BE USED IN THESE TESTS SHALL BE CONTINUOUSLY VARIABLE FROM 500 VOLTS TO 1500 VOLTS AT 1 MILLIAMPERE. THE PEAK TO PEAK RIPPLE OR ANY OTHER NOISE COMPONENT MUST BE LESS THAN 150 MILLIVOLTS OVER THE RANGE FROM 500 VOLTS TO 1500 VOLTS. THE HIGH VOLTAGE REQUIRED IN EACH TEST IS THAT VOLTAGE APPEARING AT THE OUTPUT OF THE HIGH VOLTAGE POWER SUPPLY AND THIS VOLTAGE MUST BE KNOWN TO AN ACCURACY OF $\pm 0.5\%$.

4.5 PREPRODUCTION INSPECTION AND TESTING. THE TEN (10) PREPRODUCTION SAMPLES SHALL BE SUBMITTED BY THE CONTRACTOR FOR INSPECTION AND TESTING BY THE GOVERNMENT TO INSURE THAT ALL THE SPECIFICATION REQUIREMENTS ARE MET. IN ADDITION, THE CONTRACTOR MUST SUBMIT WITH HIS SAMPLES CERTIFICATION OF THE MATERIALS USED IN THE CONSTRUCTION OF THIS TUBE.

4.6 INITIAL PRODUCTION INSPECTION AND TESTING. THE TESTING AND INSPECTION AS DESCRIBED HEREIN SHALL BE PERFORMED IN THE PRESENCE OF THE GOVERNMENT QUALITY CONTROL REPRESENTATIVE. THE INITIAL PRODUCTION TESTING SHALL BE PERFORMED IN THE CONTRACTOR'S PLANT USING HIS FACILITIES AND A WRITTEN REPORT OF THE RESULTS SHALL BE SUBMITTED TO THE CONTRACTING OFFICER FOR APPROVAL. THE TEST REPORT SHALL BE CERTIFIED AS CORRECT BY BOTH THE CONTRACTOR AND A GOVERNMENT REPRESENTATIVE. A RANDOM SAMPLE OF AT LEAST TWENTY (20) GM TUBES SHALL BE SELECTED BY THE GOVERNMENT QUALITY CONTROL REPRESENTATIVE FROM THE INITIAL PRODUCTION RUN OF 300 UNITS FOR TEST AND INSPECTION. FIVE (5) OF THESE TUBES SHALL BE TESTED IN ACCORDANCE WITH 4.6.11, FIVE (5) IN ACCORDANCE WITH 4.6.12, AND THE REMAINDER SHALL BE TESTED FOR ALL THE OTHER REMAINING TEST REQUIREMENTS.

4.6.1 BACKGROUND AND CONTAMINATION. USING THE SPECIAL TEST CIRCUIT, HIGH VOLTAGE SUPPLY, AND SCALER OF PARAGRAPH 4.4.2, THE TUBE SHALL MEET THE REQUIREMENTS OF PARAGRAPH 3.3.2. THE TUBE SHALL BE MOUNTED HORIZONTALLY WITHIN AN ENCLOSURE OF TWO INCHES OF LEAD AND $\frac{1}{4}$ INCH OF ALUMINUM WITH THE ALUMINUM FACING THE TUBE. THE COUNTING TIME SHALL BE AT LEAST FIVE MINUTES.

4.6.2 ACCURACY OF COUNT RESPONSE. USING THE SPECIAL TEST CIRCUIT, HIGH VOLTAGE SUPPLY, AND SCALER OF PARAGRAPH 4.4.2, THE TUBE SHALL MEET THE REQUIREMENTS OF PARAGRAPH 3.4. THE COUNTING TIME FOR EACH MEASUREMENT SHALL BE THREE MINUTES OR A PERIOD LONG ENOUGH TO ACCUMULATE 10,000 COUNTS, WHICHEVER OCCURS FIRST.

4.6.3 HYSTERESIS AND RADIATION DAMAGE. USING THE SPECIAL TEST CIRCUIT, HIGH VOLTAGE SUPPLY, AND SCALER OF PARAGRAPH 4.4.2, THE TUBE SHALL MEET THE REQUIREMENTS OF PARAGRAPH 3.5. THE COUNTING TIME FOR EACH MEASUREMENT SHALL BE THREE MINUTES, OR A PERIOD LONG ENOUGH TO ACCUMULATE 10,000 COUNTS, WHICHEVER OCCURS FIRST.

4.6.4 JAMMING. USING THE SPECIAL TEST CIRCUIT, HIGH VOLTAGE SUPPLY, AND SCALER OF PARAGRAPH 4.4.2, THE TUBE SHALL MEET THE SPECIFICATIONS OF PARAGRAPH 3.6. THE COUNTING TIME FOR EACH MEASUREMENT SHALL BE THREE MINUTES OR A PERIOD LONG ENOUGH TO ACCUMULATE 10,000 COUNTS, WHICHEVER OCCURS FIRST.

4.6.5 EFFECTIVE DEAD TIME. USING THE SPECIAL TEST CIRCUIT, HIGH VOLTAGE SUPPLY, AND OSCILLOSCOPE OF PARAGRAPH 4.4.2, THE TUBE SHALL MEET THE REQUIREMENTS OF PARAGRAPH 3.3.3. THE NECESSARY OSCILLOSCOPE TRACE AND DEFINITION OF DEAD TIME ARE GIVEN ON ATTACHMENT "C".

4.6.6 SHORT TERM STABILITY. USING THE SPECIAL TEST CIRCUIT, HIGH VOLTAGE SUPPLY, AND SCALER OF PARAGRAPH 4.4.2, THE TUBE SHALL MEET THE REQUIREMENTS OF PARAGRAPH 3.3.4. THE TUBE UNDER TEST SHALL HAVE HAD NO HIGH VOLTAGE APPLIED TO IT FOR A PERIOD OF THREE HOURS PRECEDING THE BEGINNING OF THE TEST. THE SPECIAL TEST CIRCUIT, THE HIGH VOLTAGE SUPPLY, AND THE SCALER SHALL BE TURNED ON AT LEAST 10 MINUTES PRIOR TO THE BEGINNING OF THE TEST. THE FIRST COUNT SHALL BE TAKEN WITHIN ONE MINUTE AFTER THE TUBE HAS BEEN INSERTED INTO THE TEST SOCKET AND PLACED IN A UNIFORM GAMMA RADIATION FIELD OF 50 MR/HR. AFTER THE TUBE HAS OPERATED IN SAID FIELD FOR ONE HOUR, THE SECOND COUNT SHALL BE TAKEN AND IT SHALL EQUAL THE FIRST COUNT $\pm 5\%$. COUNTING TIME FOR EACH MEASUREMENT SHALL BE THREE MINUTES OR A PERIOD SUFFICIENT TO ACCUMULATE 10,000 COUNTS, WHICHEVER OCCURS FIRST.

4.6.7 TEMPERATURE OPERATION. THE TUBE SHALL BE EXPOSED TO A NOMINAL GAMMA RADIATION INTENSITY OF BETWEEN 5 MR/HR AND 20 MR/HR, THE VOLTAGE APPLIED FOR A PERIOD OF AT LEAST THREE MINUTES, AND AN INITIAL RESPONSE COUNT TAKEN. THE TUBE, WHILE STILL EXPOSED TO THE SAME FIELD AND OPERATING, SHALL BE SUBJECTED TO THE TEMPERATURE EXTREMES OF -10° F AND $+130^{\circ}$ F ($\pm 5^{\circ}$ F) FOR A PERIOD OF AT LEAST THREE (3) HOURS AT EACH EXTREME. AT THE END OF EACH TEMPERATURE CYCLE, A COUNT SHALL BE MADE. THE RESPONSE RATE AT THE TEMPERATURE EXTREMES SHALL BE WITHIN $\pm 5\%$ OF THE RESPONSE RATE AT ROOM TEMPERATURE FOR A COUNTING TIME SUFFICIENT TO ACCUMULATE 10,000 COUNTS.

4.6.8 TEMPERATURE, STORAGE. THE TUBE SHALL BE STORED AT THE TEMPERATURE EXTREMES OF -50° F AND $+160^{\circ}$ F ($\pm 5^{\circ}$ F) FOR A 24-HOUR PERIOD AT EACH EXTREME. ONE HOUR AFTER THE TUBE HAS BEEN RETURNED TO ROOM TEMPERATURE FROM EACH EXTREME, COUNT RATE RESPONSE AT 5 MR/HR SHALL BE WITHIN $\pm 5\%$ OF THE COUNT RATE RESPONSE PRIOR TO PERFORMING THIS TEST. THE TUBE SHALL BE PLACED IN THE SPECIFIED GAMMA FIELD AND THE SPECIFIED VOLTAGE APPLIED FOR A PERIOD OF AT LEAST THREE MINUTES BEFORE EACH COUNT IS TAKEN. THE COUNTING TIME FOR EACH MEASUREMENT SHALL BE THREE MINUTES OR A PERIOD LONG ENOUGH TO ACCUMULATE 10,000 COUNTS, WHICHEVER OCCURS FIRST.

4.6.9 SHOCK. THE TUBES SHALL BE INSTALLED IN CDV-700 STANDARD PROBES AND MOUNTED ON A 1/8 INCH THICK STEEL PLATE 3 FEET 6 INCHES BY 2 FEET 6 INCHES IN SIZE. THE PLATE SHALL BE SHOCKED IN ACCORDANCE WITH MIL-S-901, EXCEPT THAT THE 5 FOOT HAMMER BLOW SHALL NOT BE PERFORMED. THE TUBE SHALL BE IN OPERATING CONDITION AND THE COUNT RATE RESPONSE AFTER COMPLETION OF THE TEST SHALL BE WITHIN $\pm 10\%$ AT 5 MR/HR OF THE COUNT RATE RESPONSE BEFORE THE TEST. THE COUNTING TIME FOR EACH MEASUREMENT SHALL BE THREE MINUTES OR A PERIOD LONG ENOUGH TO ACCUMULATE 10,000 COUNTS, WHICHEVER OCCURS FIRST.

4.6.10 VIBRATION. THE TUBE, MOUNTED HORIZONTALLY IN A STANDARD CDV-700 PROBE SHALL BE SUBJECTED TO THE VIBRATION REQUIREMENTS OF PARAGRAPH 3.9 ALONG EACH OF THE THREE PRINCIPLE AXES IN ACCORDANCE WITH MIL-STD-202, METHOD 201 A FOR A PERIOD OF TWO (2) HOURS IN AN OPERATING CONDITION. AT THE COMPLETION OF TESTING, THE TUBES TESTED SHALL HAVE A COUNT RATE RESPONSE WITHIN $\pm 5\%$ OF THE COUNT RATE RESPONSE BEFORE TESTING FOR A THREE (3) MINUTE COUNTING TIME OR 10,000 COUNTS, WHICHEVER OCCURS FIRST.

4.6.11 OPERATING LIFE. THE TUBE SHALL BE OPERATED IN A GAMMA RADIATION INTENSITY OF 1.0 MR/HR FOR A PERIOD OF 500 HOURS. AT THE COMPLETION OF THE TEST, THE TUBE SHALL HAVE A COUNT RATE RESPONSE WITHIN $\pm 10\%$ OF THE COUNT RATE RESPONSE BEFORE THE TEST. THE COUNTING TIME FOR EACH MEASUREMENT SHALL BE TWENTY MINUTES OR A PERIOD LONG ENOUGH TO ACCUMULATE 10,000 COUNTS, WHICHEVER OCCURS FIRST.

4.6.12 SHELF LIFE. AFTER STORAGE OF THE TUBE FOR A PERIOD OF 60 DAYS, THE TUBE SHALL BE SUBJECTED TO AND SHALL MEET THE REQUIREMENTS OF THE FOLLOWING TEST PARAGRAPHS: 4.6.1, 4.6.2, 4.6.3.

4.6.13 PRESSURE OPERATION. THE TUBE IN OPERATING CONDITION SHALL BE EXPOSED TO A GAMMA RADIATION INTENSITY OF BETWEEN 5MR/HR AND 20 MR/HR IN AN ALTITUDE CHAMBER AND, AFTER A PERIOD OF AT LEAST THREE MINUTES, A RESPONSE COUNT TAKEN. THE COUNTING TIME SHALL BE TWO (2) MINUTES OR A PERIOD LONG ENOUGH TO ACCUMULATE 10,000 COUNTS, WHICHEVER OCCURS FIRST. THE CHAMBER PRESSURE SHALL BE REDUCED TO THE EQUIVALENT OF 20,000 FEET ABOVE SEA LEVEL. AFTER TWO (2) HOURS AT REDUCED PRESSURE, THE COUNT RATE RESPONSE SHALL BE WITHIN $\pm 5\%$ OF THE COUNT RATE RESPONSE AT NORMAL ATMOSPHERIC PRESSURE WITH THE SAME EXPOSURE AND COUNTING RATE.

4.6.14 BETA RESPONSE. THE TUBE IN OPERATING CONDITION SHALL BE PLACED IN THE OCD TEST FIXTURE AND A FIVE (5) MINUTE RESPONSE TAKEN. THE RESULT OF THIS COUNT SHALL BE WITHIN $\pm 10\%$ OF THE COUNT RATE RESPONSE INDICATED FOR THE FIXTURE. A PURPOSE OF THIS TEST IS TO CHECK THE 30 MG/CM² WALL THICKNESS FOR THE BETA WINDOW.

4.6.15 MARKING AND IDENTIFICATION. THE TUBE SHALL BE CHECKED FOR CONFORMANCE WITH PARAGRAPH 3.12.

4.6.16 CONSTRUCTION AND SIZE. THE TUBE SHALL BE CHECKED FOR CONFORMANCE WITH PARAGRAPH 3.13.

4.6.17 REPORTS. A REPORT OF THE RESULTS OF THIS TESTING MUST BE SUBMITTED TO THE CONTRACTING OFFICER FOR APPROVAL PRIOR TO BEGINNING PRODUCTION OF THE TUBE.

4.7 PRODUCTION INSPECTION AND TESTING. THE GOVERNMENT QUALITY CONTROL REPRESENTATIVES SHALL BE PRESENT TO INSPECT AND OBSERVE THE TESTING OF EACH LOT OF TUBES FOR WORKMANSHIP AND CONFORMANCE WITH THE SPECIFICATION REQUIREMENTS. THE CONTRACTING OFFICER RESERVES THE RIGHT TO REMOVE SAMPLES FROM PRODUCTION FOR TESTING AND DETERMINING CONFORMANCE TO THESE SPECIFICATIONS. DEFECTIVE LOTS SHALL BE THOROUGHLY SCREENED AND RESUBMITTED AT THE CONTRACTOR'S EXPENSE. ALL PRODUCTION SAMPLES SHALL BE TESTED AND INSPECTED AS FOLLOWS:

4.7.1 PHYSICAL INSPECTION, THE FOLLOWING INSPECTIONS SHALL BE CARRIED OUT ON EACH LOT OF TUBES SUBMITTED FOR ACCEPTANCE WITH AN AQL 0.40 PER CENT USING GENERAL INSPECTION LEVEL III:

4.7.1.1 INSPECTION FOR BENT OR BROKEN PINS, DAMAGED SEALS, AND OTHER PHYSICAL DEFECTS.

4.7.1.2 PROPER MARKING AND IDENTIFICATION IN ACCORDANCE WITH PARAGRAPH 3.12.

4.7.2 INSPECTION OF PACKAGING, EACH LOT SHALL BE SAMPLED AND INSPECTED FOR ADEQUACY OF PACKAGING AS FOLLOWS WITH AN AQL 0.40 PER CENT USING GENERAL INSPECTION LEVEL III:

4.7.2.1 CHECK TO INSURE THAT EACH SHIPPING CONTAINER CONTAINS ONE HUNDRED (100) INDIVIDUALLY PACKAGED TUBES.

4.7.2.2 INSPECT INDIVIDUAL TUBE CONTAINERS TO INSURE THAT IT IS UNDAMAGED AND MEETS THE REQUIREMENTS OF PARAGRAPHS 5.1 AND 5.3.

4.7.2.3 INSPECT OUTSIDE SHIPPING CONTAINER TO INSURE THAT IT IS UNDAMAGED AND MEETS THE REQUIREMENTS OF PARAGRAPH 5.2 AND 5.3.

4.7.3 TESTS, THE FOLLOWING TESTS SHALL BE PERFORMED ON EACH LOT OF TUBES SUBMITTED FOR ACCEPTANCE WITH AN AQL OF 0.65 PERCENT USING GENERAL INSPECTION LEVEL II. THE TESTING SHALL BE PERFORMED BY THE OCD/STRATCOM INSTRUMENTATION TEST FACILITY OR OTHER GOVERNMENT FACILITY.

(A) **4.6.1 BACKGROUND AND CONTAMINATION,**

(B) **4.6.2 ACCURACY OF COUNT RESPONSE MODIFIED TO INCLUDE ONLY THE 5 MR/HR, 925 VOLT MEASUREMENT.**

(C) **4.6.17 CONSTRUCTION AND SIZE,**

(D) **4.6.5 EFFECTIVE DEAD TIME.**

(E) **4.6.6 SHORT TERM STABILITY,**

(F) **4.6.12 STORAGE TESTS,** THE STORAGE TEST OF 4.6.12 SHELF LIFE EXCEPT MODIFIED TO 30 DAYS OF STORAGE, AND REPEAT PARAGRAPHS 4.6.1 AND 4.6.2.

4.8 SPECIAL TESTS. THE FOLLOWING TESTS SHALL BE PERFORMED ON EACH LOT OF TUBES SUBMITTED FOR ACCEPTANCE WITH AN AQL OF 0.65 PER CENT USING SPECIAL INSPECTION LEVEL S-4. THE TESTING SHALL BE PERFORMED BY THE OCD/STRATCOM INSTRUMENTATION TEST FACILITY OR OTHER GOVERNMENT FACILITY.

- (A) 4.6.2 ACCURACY OF COUNT RESPONSE. (ENTIRE TEST)
- (B) 4.6.4 JAMMING.
- (C) 4.6.7 TEMPERATURE OPERATION.
- (D) 4.6.8 TEMPERATURE STORAGE.
- (E) 4.6.14 BETA RESPONSE.

4.9 OPTIONAL TESTS. THE GOVERNMENT RESERVES THE RIGHT OF TESTING ALL PRODUCTION LOTS SUBMITTED ACCORDING TO THE REQUIREMENTS OF PARAGRAPH 4.6, INITIAL PRODUCTION INSPECTION AND TESTING. THE TESTING, IF IT IS DONE, SHALL BE PERFORMED BY THE OCD/STRATCOM INSTRUMENTATION TEST FACILITY OR OTHER GOVERNMENT FACILITY WITH AN AQL OF 4.0 PER CENT USING SPECIAL INSPECTION LEVEL S-4.

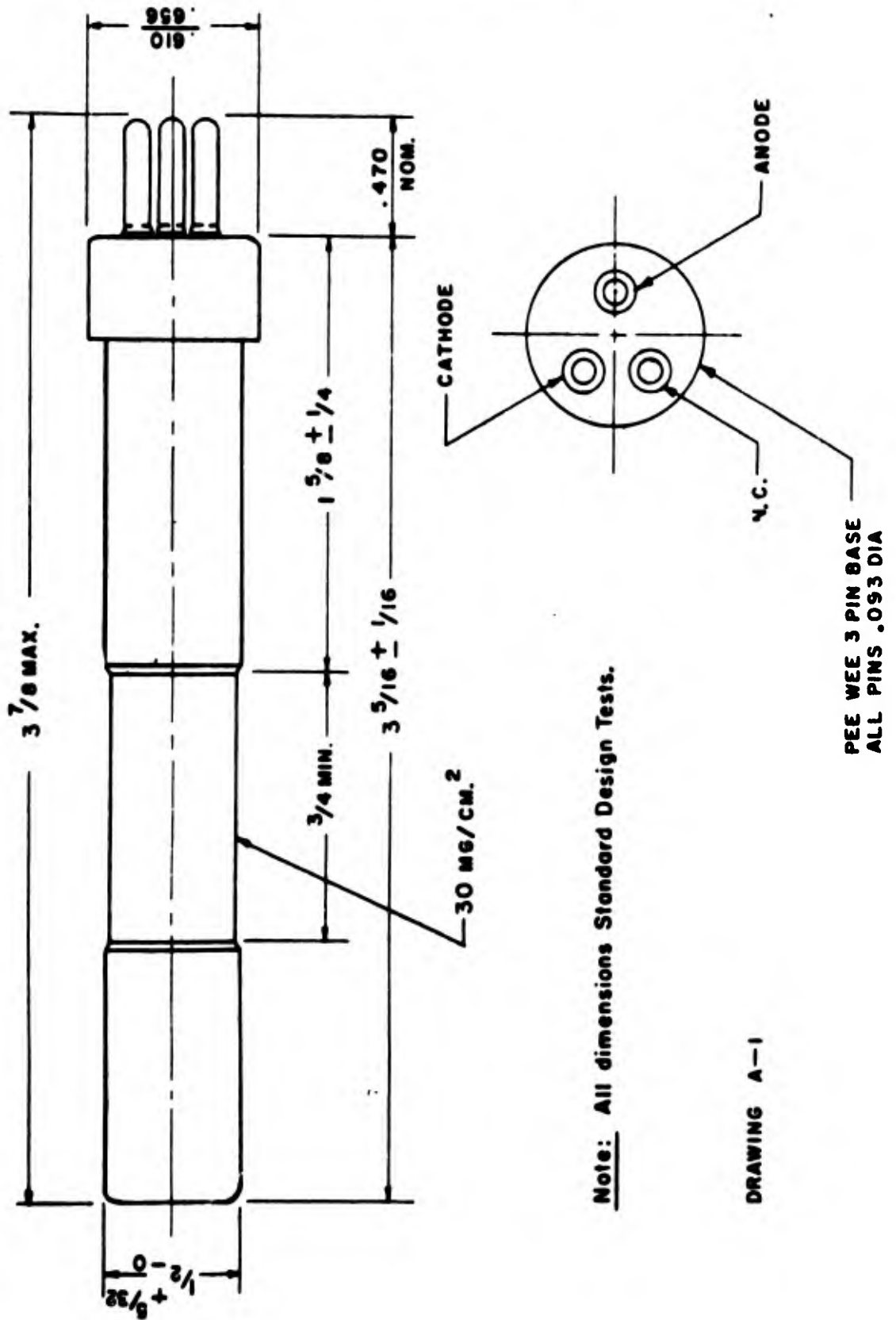
5. PACKING AND MARKING

5.1 EACH TUBE SHALL BE INDIVIDUALLY BOXED IN A DOUBLE-FACED CORRUGATED FIBERBOARD CONTAINER WITH A BURSTING STRENGTH OF NOT LESS THAN 175 POUNDS, CONFORMING TO FEDERAL SPECIFICATIONS PPP-B-636.

5.2 ONE HUNDRED INDIVIDUALLY BOXED TUBES SHALL BE PACKAGED IN AN OUTSIDE SHIPPING CONTAINER. THIS CONTAINER SHALL BE A STANDARD COMMERCIAL CONTAINER OF DOUBLE-FACED CORRUGATED FIBERBOARD, WITH A BURSTING STRENGTH OF NOT LESS THAN 275 POUNDS, CONFORMING TO FEDERAL SPECIFICATION PPP-B-636.

5.3 EACH BOX AND EACH OUTSIDE SHIPPING CONTAINER SHALL BE MARKED WITH THE FOLLOWING INFORMATION: "GEIGER-MUELLER TUBE", "OCD ITEM NO. OCD-D-103", THE CONTRACT NUMBER AND THE MANUFACTURER'S NAME. THE OUTSIDE SHIPPING CONTAINER SHALL ALSO BE MARKED WITH THE SHIPPING WEIGHT AND "CONTAINS 100 TUBES". THE MARKING AND PACKING SHALL BE SUBMITTED FOR APPROVAL TO THE CONTRACTING OFFICER PRIOR TO BEGINNING INITIAL PRODUCTION.

ATTACHMENT A
GM TUBE SPECIFICATION

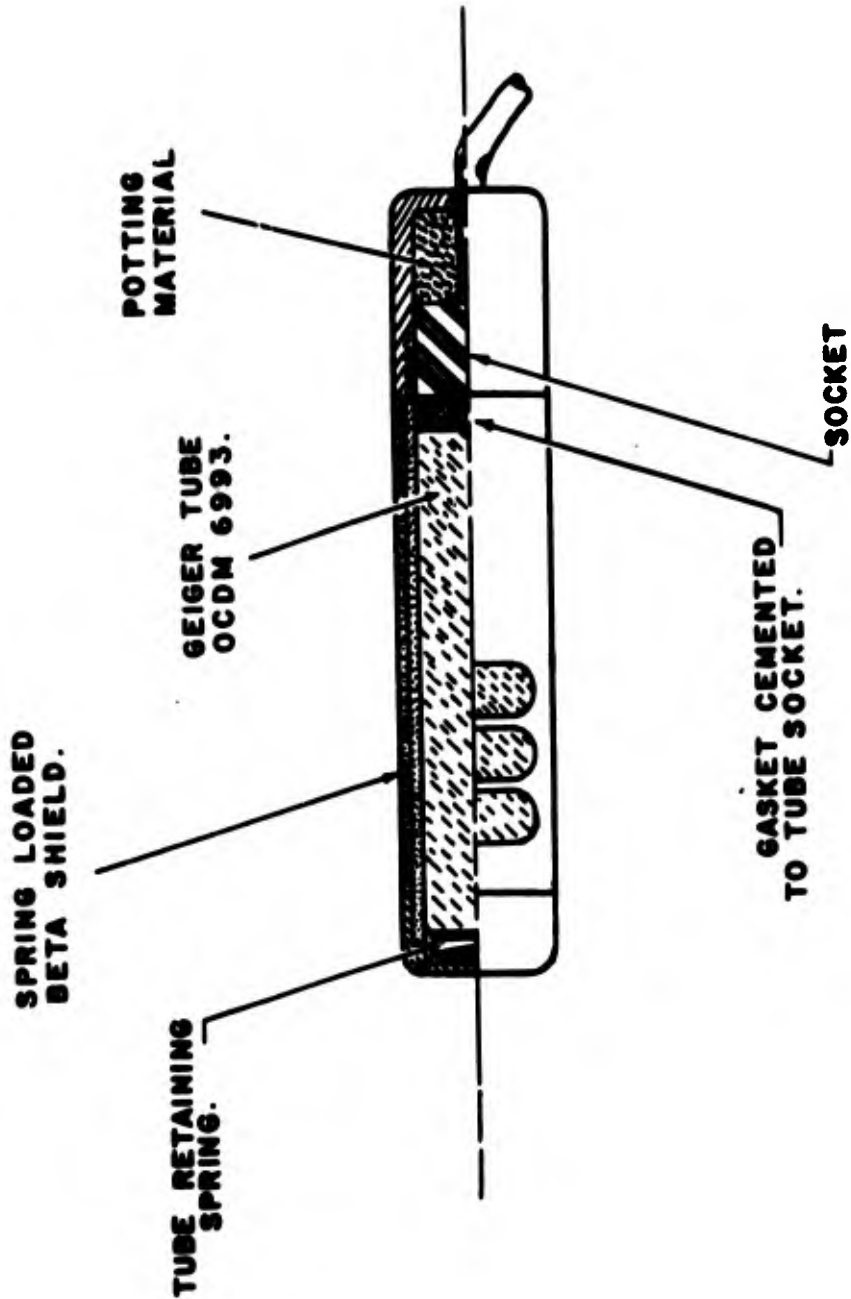


Note: All dimensions Standard Design Tests.

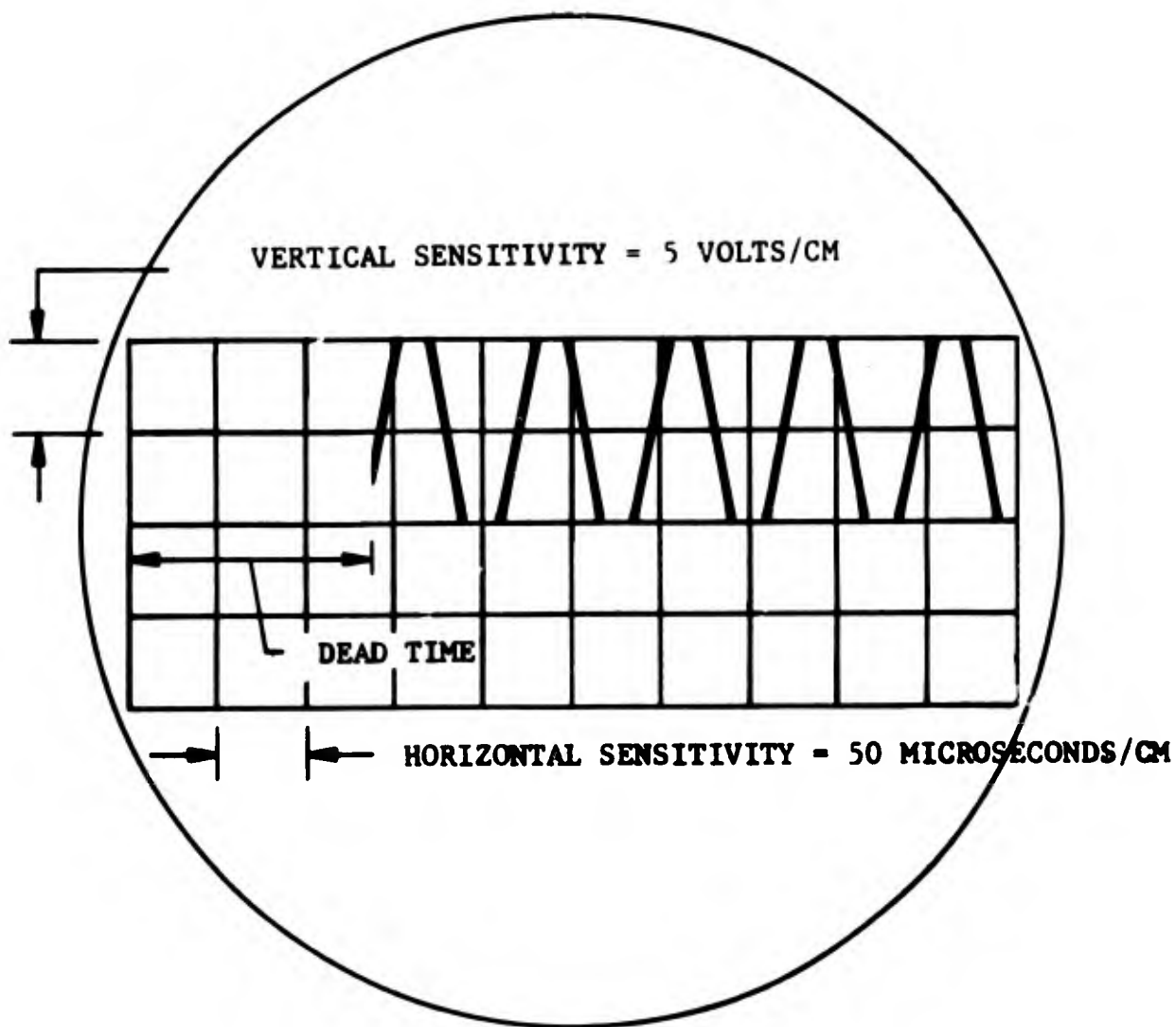
DRAWING A-1

PEE WEE 3 PIN BASE
ALL PINS .093 DIA

ATTACHMENT B
PROBE ASSEMBLY
FOR
RADIOLOGICAL SURVEY METER



ATTACHMENT C

OSCILLOSCOPE TRACE TO BE USED FOR CHECKING DEAD TIME
REQUIREMENTS OF PAR. 3.3.3

NOTE: OSCILLOSCOPE MUST BE TRIGGERED ON INTERNAL NEGATIVE SLOPE.