Longevity Performance of Cesium Beam Frequency Standards

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LONGEVITY PERFORMANCE OF CESIUM BEAM FREQUENCY STANDARDS

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Abstract

The results are reported of a survey conducted to assess the useful lifetime performance of Cesium Beam Frequency Standards. The source sample includes organizations which operate Cesium Beam Frequency Standards in support of timekeeping, space tracking, communications, navigation and calibration.

Also, presented is an analysis of the lifetimes of various Cesium Beam Tubes, the major component within the Cesium Beam Frequency Standard. The data for this analysis are taken from the records of the Hewlett-Packard Company.

Introduction

The review of Cesium Beam Frequency Standard performance in field operation was undertaken to provide a statistical base for sound planning and programming of future operational requirements and to provide visibility of maintenance/repair requirements.

The information presented in this paper is the result of the joint, yet separate efforts, of the U.S. Naval Observatory and Hewlett-Packard Company.

a. The U.S. Naval Observatory portion is based on the results of the response to a questionnaire, which was sent to addresses selected at random from the U.S. Naval Observatory mail list.

b. The Hewlett-Packard portion is based on the result of an in-house review of the maintenance service records with regards to cesium beam tube replacement. The data base includes the entire population of Cesium Beam Tubes, produced since 1968 and used in HP Model 5061A and HP Model 5062C Cesium Beam Frequency Standard.

Field Survey

Questionnaire:

The questionnaire (Figure 1) used by the U.S. Navy Observatory included provisions for the following information:

1. Reporting Activity:
2. Control No: - Admin Control
3. Model No.
4. Serial No.
5. Service Date - Initial date placed in service (new or after repair)
6. Failure Date - Date of fault reported
7. Repair Date - Date of repair of reported fault
8. Application
9. Fault Location

Responses to questionnaire were received from a cross section of the international time/frequency community to include elements of communications, navigation, satellite tracking, calibration and national standards laboratories.

Of the ninety-one questionnaires mailed, thirty-eight responses were received as of 7 May 1980. Of these, twenty-six provided useful information on a total of seventy-four cesium-beam oscillators (HP 5061). No other model is covered in the current field survey report.

Results.

Though relatively small, this sample reveals some interesting data. First a look at the number of failures against time (Figure 2). Note the age of the oldest reported oscillator is a bit over twelve years. The other notable items on this graph is the high initial failure rate which is again matched in the third year. Then it tends to taper and level off at around five failures per year.

The plot of failures by type module (Figure 3) reveals that the high non-performers are the A2 battery charger, A9 Operational Amplifier and the A12 cesium beam tube. However, with a larger sample these rankings may change.

The cesium beam tube total may be out of proportion yet realistic because better records both maintenance and procurement are available on high dollar items. While the less expensive items may be routinely processed through maintenance and procurement channels.

Another highlight is the other category which included A16 Clock Assembly, A17 Terminal Board, A18 +3500 VDC power supply, A19 -2500 VDC power supply and other stoppages.

The Phase Detector module A8 appears to be the most reliable, note that no failures were reported for this module.

The cost of the modules and module identification are shown for information (Figure 4). There is no apparent relation between cost and failures or reliability. In one case the high cost item was the item on which the failure reports were also high. The A2, A9 and A12 failures are presented on the next three plots. For the A12, Cesium Beam Tube (Figure 5), it appears that after the initial failures, there is a year or two of low failure.

I suspect that the third-year lump is due to the new high performance tubes and the second lump at five years is the regular tube.

The A2, battery charger (Figure 6), appears to suffer the high initial failure and like the A12 cesium beam tube, it then enjoys a year of low failures and increases in second and third years. After the middle of the fourth year there were few significant failures.

The A9 Operational Amplifier (Figure 7), seems to have a rather flat failure rate still loaded toward the early years.

The plot of Other Failures (Figure 8), against time is interesting only in that it does not show the high initial rate and more closely reflects the curve one would like to see. This may be due to the fact that it is a catchall for random failures. Note that its peak in the first six months of the fourth year lags.

The data presented has not been averaged. It is simply a tabulation of information collected. An attempt was made to remove all non-operational time from the service time. When a module was repaired or replaced it started as a new item with zero service time.

Cesium Beam Tube Longevity

This portion of the paper will discuss the Beam Tube, the single most expensive item within the Frequency Standard. The reliability and, even more importantly, the lifetime of the beam tube is of prime importance to the user because it is a perishable item. The beam tube does, in fact, have a finite intrinsic lifetime due to the nature of the physics of the device.

This analysis of the beam tube lifetime data includes all of the beam tubes produced by HP since 1968, when the 5061A was first introduced. We will not be discussing the older 5060A data since a number of users have opted to replace older units with the 5061A. Because of this, HP has not been getting back all of the dead beam tubes to determine their respective lifetimes. The source of the lifetime data is the shipment and return-for-credit exchnage dates less an appropriate length of time to account for shipment time and non-use time due to delays in getting the old beam tube back to HP.

We will discuss:

1. the meaning of the curves we will be using
2. the definition of a 5-7 year life
3. identify the 3 beam tubes
4. discuss the lifetime and reliability of each
5. the validity of the data.

Understanding the Curves

The format we shall use for presenting the data is as shown in Figure 9. We compare the percentage of beam tubes returned vs the age of the tube. The curve is cumulative and, therefore, we would expect it to eventually get to 100%. The question is how long before it gets there. The curves do represent the entire population of tubes and, therefore, include all failures whether catastrophic or normal end of life. The curves on the high performance tube also includes a number of tubes whose oven temperatures were purposely turned up to achieve even greater performance but at an acknowledged decrease in lifetime.

Lifetime Defined

The design life for most beam tubes is 5-7 years. This is a compromise between longevity and superior performance. We could turn up the temperature of the beam tube and improve its performance but likewise shorten the lifetime. For most applications, 5-7 years with an acceptable safety margin is the standard. We might expect - for an ideal design (dashed line Figure 9) to have no failures in the 1st 5 years. At the end of 7 years perhaps 50% would have died and the remaining 50% would die in greater than 7 years. However, due to the randomness of any manufacturing process - we expect a low percentage of beam tubes dying before 5 years. An estimate of 4%/year might be appropriate resulting in a curve which moves upward by 20% as shown in Figure 9 (solid line).

Cesium Beam Tube Characteristics

The cesium beam tube is a precision manufactured device requiring very tight tolerances and stringent requirements for cleaningness. The 3 beam tubes we shall discuss are shown in Figure 10: the mini tube, high performance and standard tubes.

Figure 11 shows the components of the 5062 mini tube as an example of the physical make-up of cesium beam tubes. The key components are the oven, state selector magnets, interactive cavity, ionizer, electron multiplier and the mass spectrometer. Other important components not shown are the Vac Ion Pump and Gettering Material.

5062C Mini Tube

The 5062C Mini Cesium Beam tube uses 12 beams of cesium and a very short interactive cavity with sufficient cesium and getting to last significantly longer than the 5 to 7 year design life. Figure 12 shows the actual life characteristics for those tubes shipped between 1974 and June 1977. In early 1977 we experienced a higher level of returns due to low beam current tube. From the failure analysis we determined the cause to be the electron multiplier. Due to the high level of beam flux the gain of the electron multiplier degraded rapidly causing death of the tube.

Owners of the instruments were informed that the Electron Multiplier Voltage and Cesium Oven Temperature needed to be turned down. As a result of that turn-down and a later retrofit of some electronics, the beam tube life was extended such that 44% of those early tubes are still in an operational status. After June of 1977 the instruments shipped from the factory included the turndown as well as the new electronics. Approximately a factor of 2 improvement in lifetime was achieved as shown by the second curves. February 1978 marked the first shipment of beam tubes from the newly rennovated clean room facility. The resultant change in lifetime performance is dramatic as shown by the bottom curve.

High Performance Beam Tube

The next beam tube we will look at is the high performance 5061A Option 004. This tube was specifically designed with a longer interactive cavity, higher beam flux (using dual beams) and greater gettering capacity than the standard tube. Its purpose is to be more accurate and have greater short term time domain stability than previously available frequency standards. Its design life was also 5 to 7 years with a large design safety margin. I might point out that it is also possibly to turn up the oven temperature in a standard beam tube to get improved performance but with significantly shorter lifetime. The Hewlett-Packard High Performance Cesium Beam Tube was specifically designed for improved performance without significantly lower life.

Figure 13 shows the early tube data. During the 1973-74 timeframe we experienced a number of early failures due to the cesium oven. This discovery resulted in an oven redesign. The beam tubes that did make it past the early problems have led useful and productive lives and after 6 1/2 years there are still more than 45% operating.

The oven redesign resulted in a better lifetime characteristic in the middle curve. The bottom curve shows the data for the beam tubes produced after the clean room facilities were rennovated. Again the same type of improvement that we had for the 5062C tube.

Standard 5061A Cesium Beam Tube

Let us now turn to the standard 5061A cesium beam tube data to see how it has performed over the years. This beam tube is also in a 16" long envelope like the HP Option 004 high performance tube or rather just the reverse since the standard tube was first introduced in the HP 5060A in 1964.

The standard HP 5061A beam tube life characteristic is interesting because it has a reputation in the industry which sets it apart from all other beam tubes regardless of manufacturer. The data on this graph explains why it has that reputation. This graph shows the beam tubes produced between April 1968 and November 1971. After 10 years there are still over 50% operational.

As we examine Figure 14 we might question the validity of the data. The owner of the 5061A, whose beam tube has failed, will normally return the old tube for credit to keep his cost to a minimum. However, a certain number of owners may not return the dead beam tube. Perhaps they want to put it on display, take the instrument out of service, or even take the beam tube apart. We estimate that fewer than 5 to 10% of the beam tubes would fall into this category. Adding to the validity of this data we find a number of tubes from this batch whose lifetime has actually been 10, 11 and, in several cases, 12 years. The data obtained directly from the users and presented earlier in this paper supports this data.

The middle curve shows those tubes produced between November 1971 and June 1974. This particular batch has a little higher rate in the early years but crosses over in the 5 3/4 year point.

The last curve shows more recent tube history. It appears that the curves for the standard tubes are fairly consistent with minor variations.

As you can see from the data for this tube, which was designed for a 5 to 7 year lifetime, it has not only exceeded our wildest expectations but has deomonstrated a lifetime in excess of 10 years for a large percentage of users.

Conclusion

The data on the cesium beam tubes has shown us some very interesting results. The standard beam tube life is exceptional. The high performance and the mini tube are performing as expected for a 5-7 year design life - now that early problems are solved.

CESIUM BEAM FREQUENCY STANDARD
PERFORMANCE DATA

REPORTING ACTIVITY:

FAULT LOCATION

CONTROL NO. ____

MODEL NUMBER	SERIAL NUMBER	SERVICE DATE	FAILURE DATE	REPAIR DATE	APPLICATION	A1-Synthesizer	A2- Battery Charger	A3-90MHz Multiplier	A4-Harmonic Generator	A5-Digital Divider	A6- Frequency Divider	A7-AC Amplifier	A8-137Hz Osc/Phase Det	A9-Operational Amplifier	A10-Crystal Oscillator	A11-Oven Controller	A12-Cesium Beam Tube	A13-Buffer Amplifier	A14-Logic	A15-Power Regulator	Other

APPLICATIONS:
1A-House Frequency Standard
1B-House Time Standard
1C-Both above
2-Portable Standard
3-Field Installation (Shore-Fixed)
4-Field Installation (Mobile-Ship,Aircraft,Etc.)

Figure 1 : Cesium Beam Frequency Standard Performance Questionnaire.

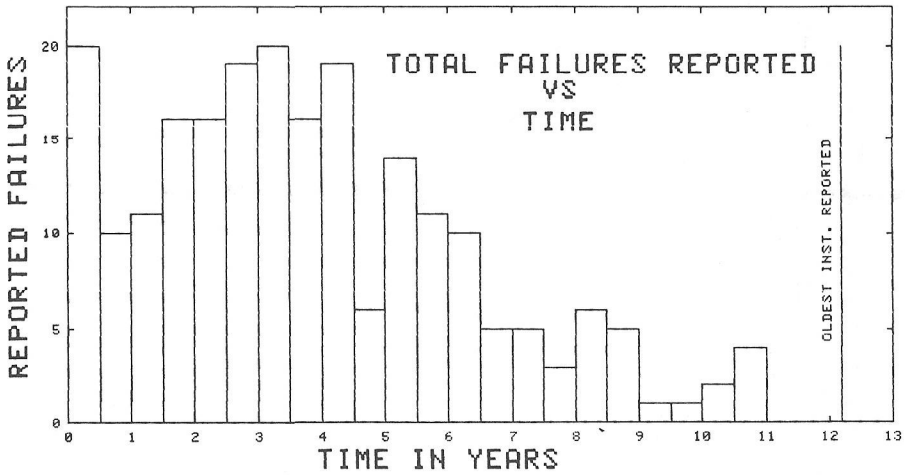

Figure 2 : Total Failures Reported vs Time.

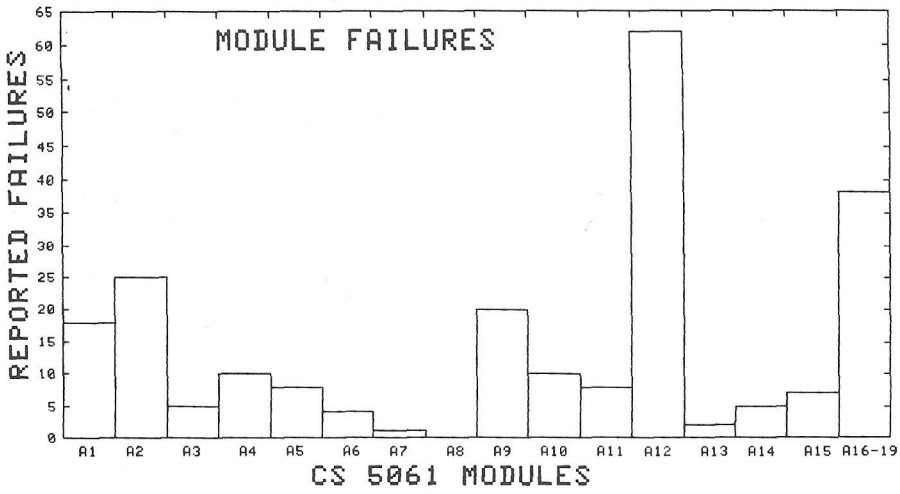

Figure 3 : Module Failures.

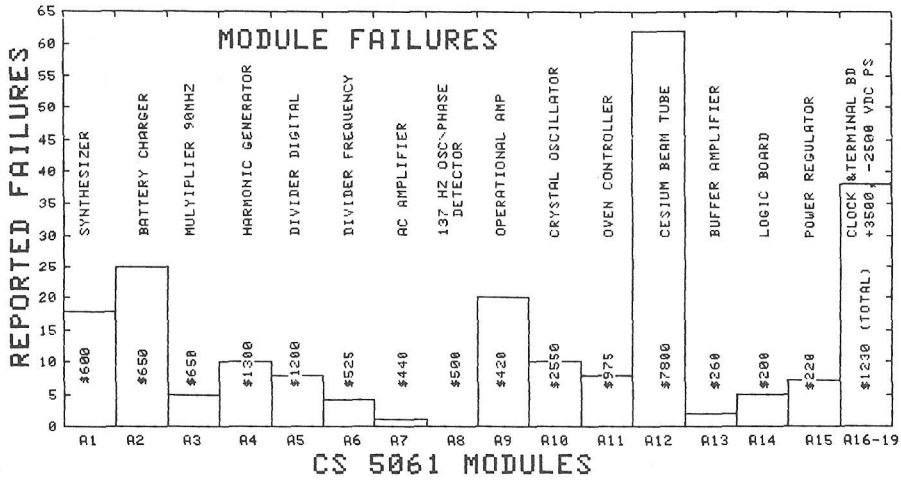

Figure 4 : Module Failures with associated costs.

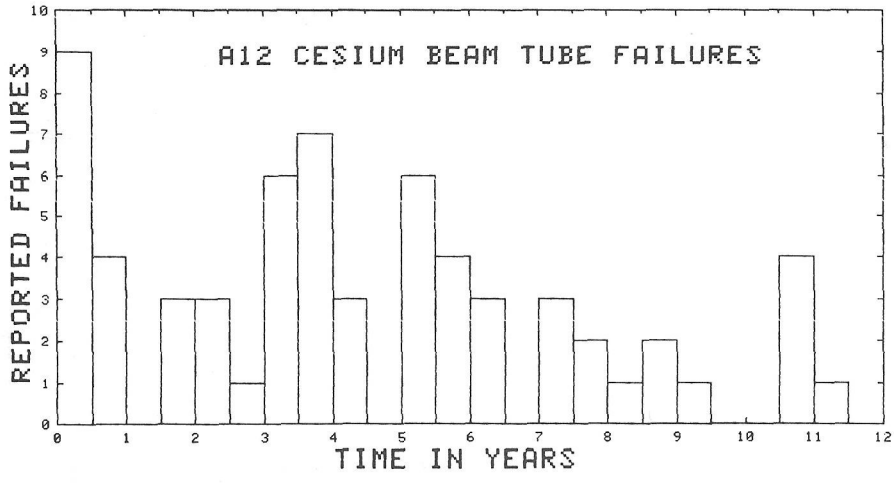

Figure 5 : A12 Cesium Beam Tube Failures.

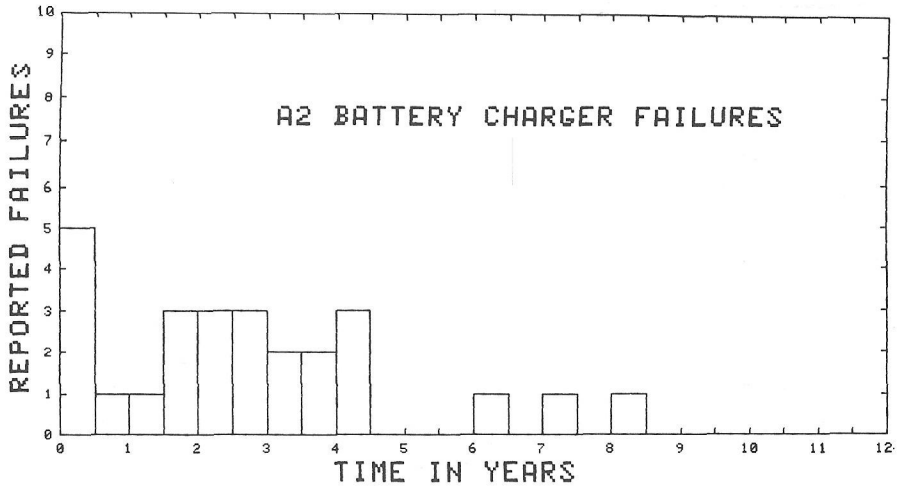

Figure 6 : A2 Battery Charger Failures.

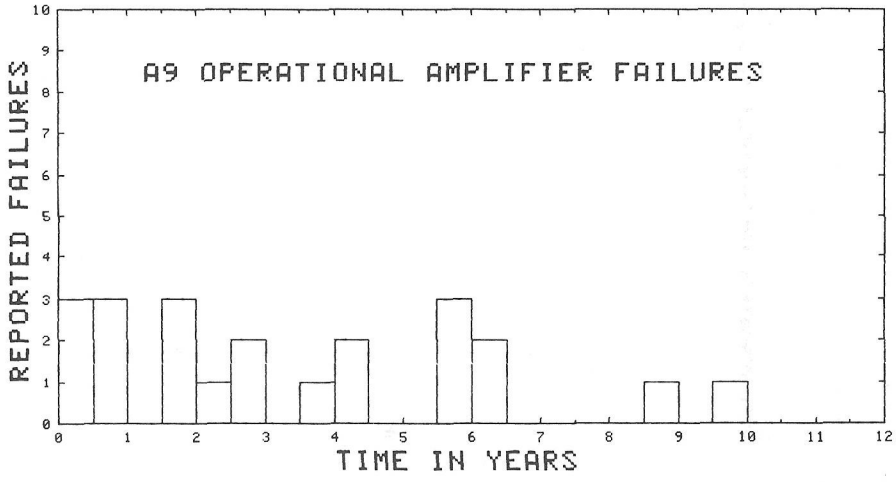

Figure 7 : A9 Operational Amplifier Failures.

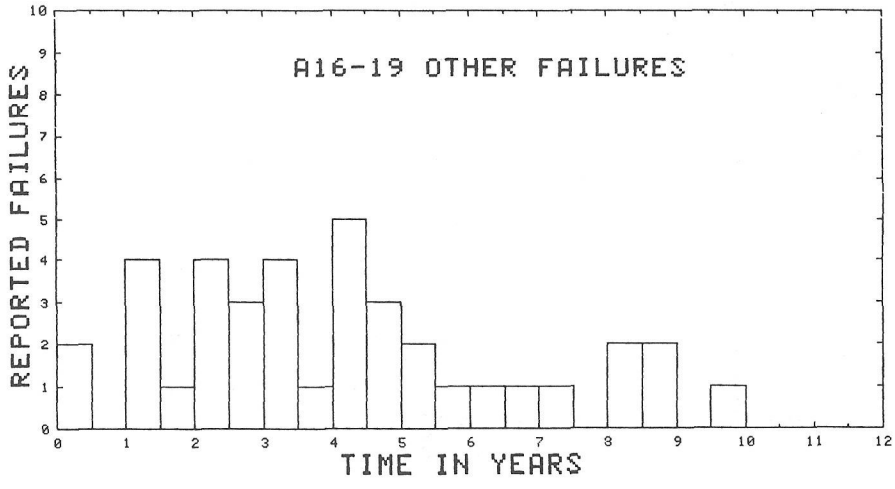

Figure 8 : A16-19 Other Failures.

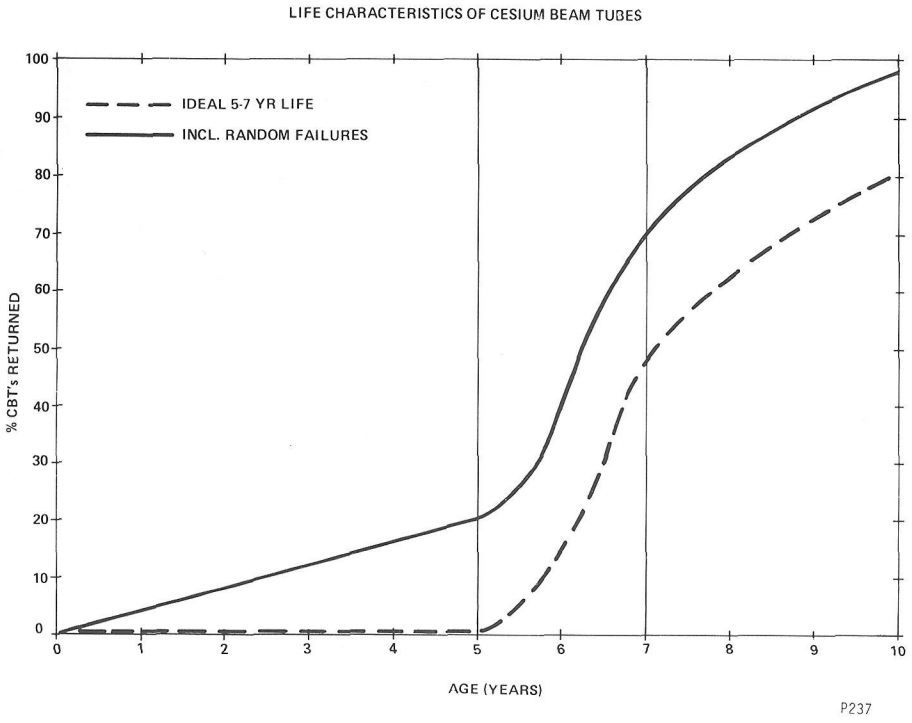

Figure 9 : Ideal 5-7 year life Characteristics of Cesium Beam Tubes.

Cesium Beam Tubes

Instrument	Beam Tube	Characteristics
HP 5062C	Mini Tube	6" long cylindrical envelope Line width: *1300* Design life: *5 to 7 years* Nr. of Beams: *12*
HP 5061A	High Performance Option 004	16" cylindrical envelope Line width: *450* Design Life: *5 to 7 years* Nr. of Beams: *2*
	Standard	16" cylindrical envelope Line width: *600* Design life: *5 to 7 years* Nr. of Beams: *1*

Figure 10 : Cesium Beam Characteristics.

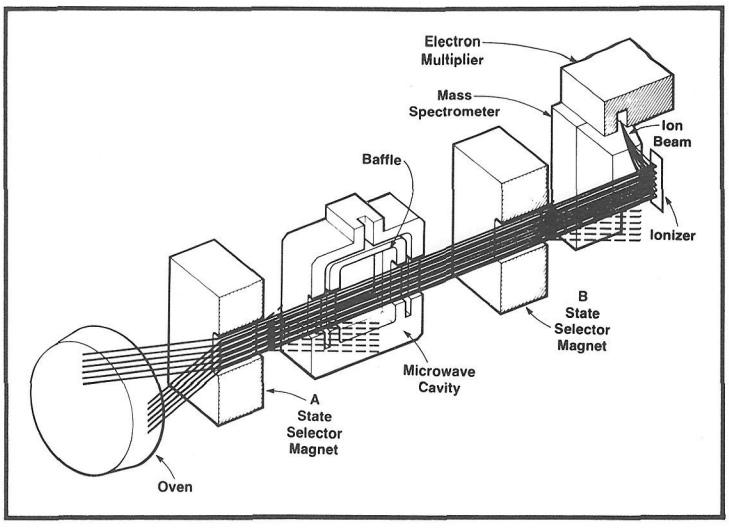

Figure 11 : Cesium Beam Tube interval components.

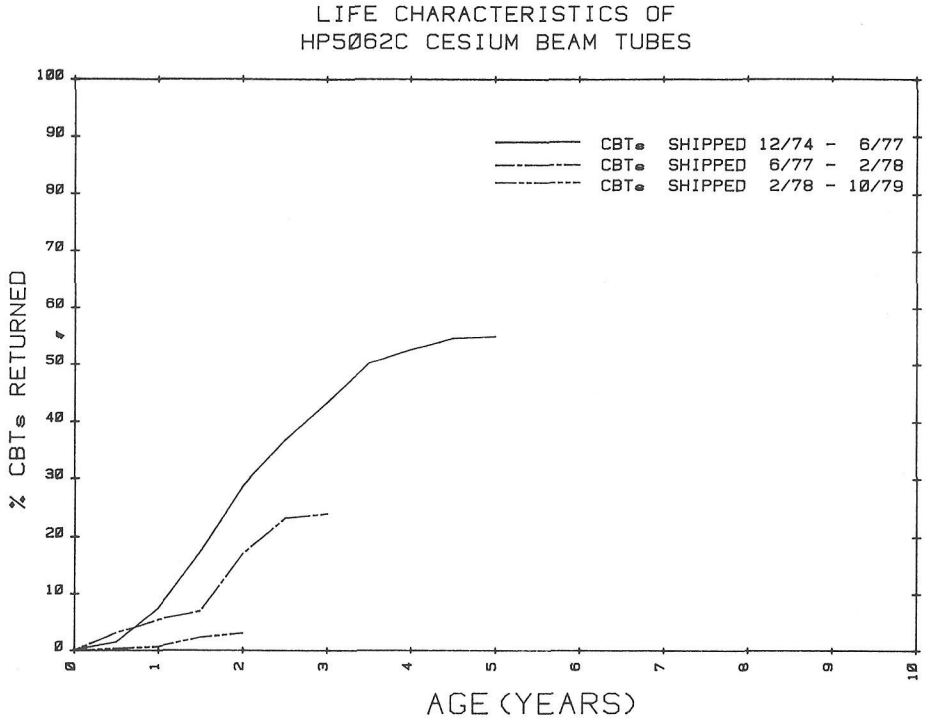

Figure 12 : Life Characteristics of HP 5062C Cesium Beam Tubes.

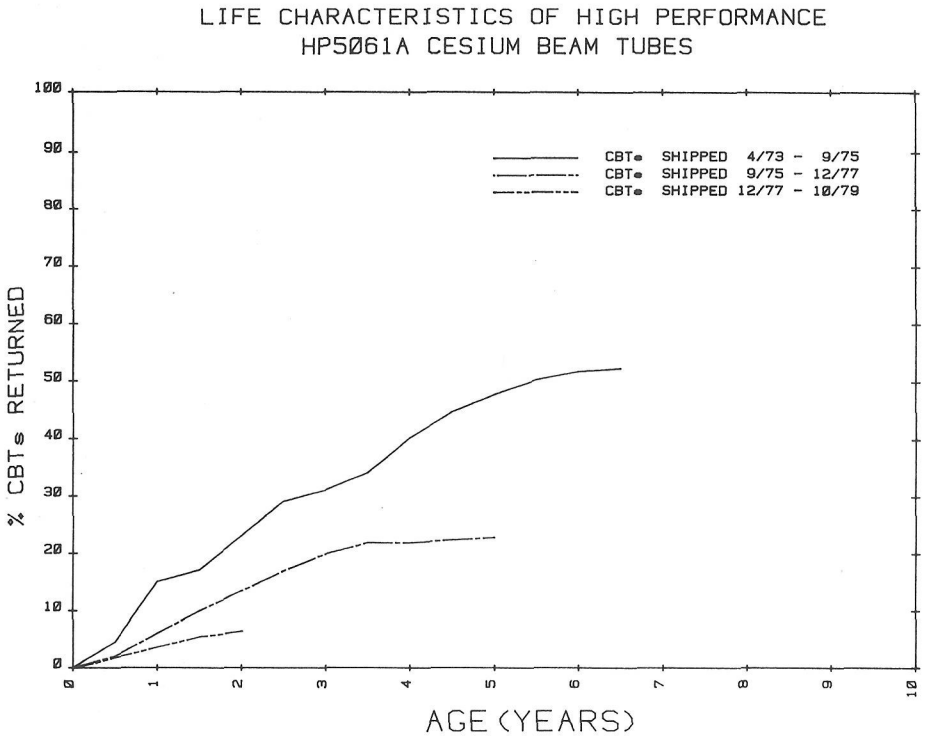

Figure 13 : Life Characteristics of High Performance HP 5061A Cesium Beam Tubes.

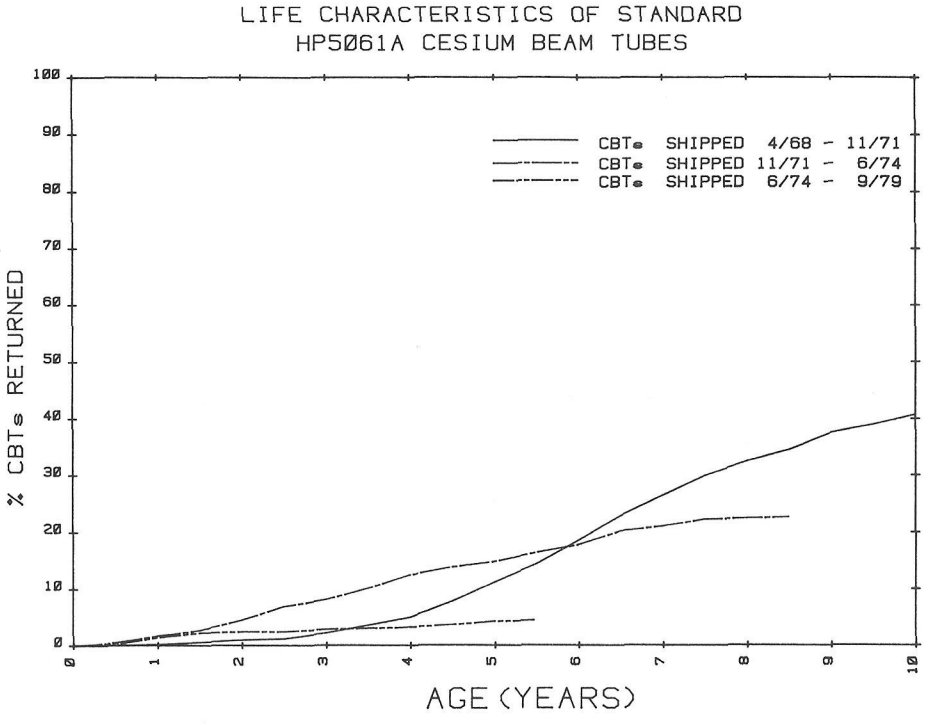

Figure 14 : Life Characteristics of Standard HP 5061A Cesium Beam Tubes.