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CONTRACT AT(30-1)-3979
ADVANCED HEAT PIPE
THERMIONIC TECHNOLOGY

MASTER

TOPICAL REPORT
FOR
TASK II
"DEVELOPMENT OF ADSORPTION RESERVOIR"

PERIOD OF PERFORMANCE
MAY 1, 1968 THROUGH FEBRUARY 28, 1969

PREPARED FOR:
U. S. ATOMIC ENERGY COMMISSION
NEW YORK OPERATIONS OFFICE
NEW YORK, NEW YORK

BY
RCA ELECTRONIC COMPONENTS
POWER DEVICES OPERATION
LANCASTER, PENNSYLVANIA

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AUTHOR - R. A. FREGGENS

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FOREWORD

This report was prepared by RCA, Lancaster, Pennsylvania under U.S. Atomic Energy Commission Contract AT(30-1)-3979 entitled, "Advanced Heat Pipe Thermionic Technology". The program of work, to date, has been monitored by Mr. Lester Price of the Space Nuclear Systems Division, Germantown, Maryland.

This Topical Report covers the work performed since program inception, 1 September 1968 through 28 February 1969. The studies and accomplishments presented herein represents the efforts of the Special Power Devices Engineering Department. Mr. W. E. Harbaugh, Project Engineering Leader, provided technical direction for the program. Mr. R. A. Freggens, Product Development Engineer, was responsible for the performance of the actual program of work.

ABSTRACT

This report covers work performed on the development of an intergral adsorption reservoir thermionic converter. Three general areas were investigated during the study. Areas studied were: cesium purification, material processing, and integral reservoir converter fabrication.

The cesium purification employed a high temperature reaction to remove halide compounds from the cesium. A study was made to develop a large surface to volume ratio in a molybdenum matrix. Variations in time, temperature, and atmosphere for sintering the matrix were used as the basis of the study.

The RCA A-1279 Thermionic Converter was selected as a suitable test vehicle for reservoir evaluation. The design was modified to allow 78 cm³ of reservoir matrix to be integrally located within the converter.

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TASK II - DEVELOPMENT OF ADSORPTION RESERVOIR
(Responsible Person - R. A. Freggens)

SECTION I

INTRODUCTION AND SUMMARY

During the final months of the preceeding AEC Contract AT(30-1)-3642, which authorized the feasibility study of a cesium adsorption reservoir converter, a problem was encountered which appeared to be associated with cesium purity and converter materials. This study program, Task II, is designed to investigate these problems.

The purification of cesium was initiated in an effort to eliminate possible halide compounds of cesium found present in the earlier adsorption reservoir converters. An integral adsorption reservoir was designed, using as a basis, the RCA Cylindrical Converter, Type A-1279. This design will serve to evaluate the integral adsorption reservoir.

The program has been divided into three phases of study and investigation. They are: Phase I - Cesium Purification, Phase II - Material Purification and, Phase III - Converter with Adsorption Reservoir.

SECTION II

PROGRAM ACCOMPLISHMENTS

Phase I Cesium Purification

The process selected for removing chlorine from the system entailed reacting Dow cesium with barium under high vacuum conditions and at high temperature (800° C). This reaction forms a tertiary compound of cesium, barium and chlorine which has a melting point of 980° C and therefore will not co-distill from the reaction capsule at 350° C when the cesium is distilled into copper vials. A photograph of the cesium dispensing still is shown in Figure 1.

Two versions of the reaction capsule were produced. The second version is shown in the lower right hand portion of Figure 1. This version was designed to remain attached to the system throughout the purification cycle. The first reaction capsule is shown in Figure 2. A cross-sectional view of this capsule, Figure 3, shows the insulation post, ground terminal and containing shell. The barium was stored in Kemet ground barium wire which was formed in a coiled-coil configuration. The ends of the wire were spot welded to the nickel rods which pass through the top plate of the capsule. The entire dispensing system was heated to 450° C for five and one-half hours under a constant vacuum pressure of 4×10^{-7} torr. Following this, the system was cooled to room temperature and the barium discharged into the reaction capsule by passing DC current through the wire. The discharged quantity of barium was independently measured by "firing" a length of Kemet wire in a vacuum bell jar and measuring the weight change. The measured value was 0.0735 grams for 6 feet of wire, the quantity used in the capsule. Figure 4 is a photomicrograph of the cross-section of the ground barium wire.

FIGURE 1 PHOTOGRAPH OF CESIUM DISPENSING STILL

FIGURE 2 PHOTOGRAPH OF FIRST REACTION CAPSULE

FIGURE 3 CROSS-SECTIONAL DRAWING OF FIRST CESIUM REACTION CAPSULE

FIGURE 4 PHOTOMICROGRAPH OF GROUND BARIUM
WIRE CROSS-SECTION (Magnification 69X)

In the first test, 20 grams of cesium was dispensed into the double sapphire window measuring container which is shown in the upper right hand corner of Figure 1. The cesium was then distilled into the first reaction capsule and the nickel "pinch-off" accomplished. The entire capsule was then heated in a vacuum bell jar using a stainless steel radiation heater as shown in Figure 5. Upon heating of the capsule, a leak developed in the "pinch-off" and cesium was discharged into the vacuum bell. To correct this problem, a second capsule was designed to remain attached to the system. A valve was inserted between the reaction capsule and the V-10 dispenser block. A photograph of this combination is shown in Figure 6. The diagrammatic cesium dispensing system, using the second capsule design, is shown in Figure 7. During the "firing" test of the barium wire, it was observed that the barium would discharge at approximately 700° C. A test was performed with a coil of wire located in a closed vessel which was heated by the radiation heater to a temperature of 800° C to thermally discharge the barium. This test was successful and the method was used to discharge the barium into the second reaction capsule. Ten feet of ground barium wire, having a barium content of 0.122 grams, was coiled in the bottom of the second reaction capsule. The cesium dispensing system was again baked at 450° C while maintaining a high vacuum of 4×10^{-7} torr. The barium was discharged from the wire into the reaction capsule by heating to 800° C. The system was cooled and cesium distilled from the Dow cesium capsule into the window vessel. Cesium was then distilled into the reaction capsule and the capsule heated to 800° C for 30 minutes. The water coil above the reaction capsule prevented escape of cesium during the reaction time. The capsule was then cooled and the valve between the V-10 dispenser block and capsule opened. The cesium was then distilled into the V-10 block and subsequently into ten 1/4 inch diameter, 6 inch long copper tubing vials. A cold weld "pinch-off" was made to seal the vial and to separate it from the dispensing block. Each vial contained between 2.38 to 2.61 grams of cesium.

FIGURE 5 PHOTOGRAPH OF STAINLESS STEEL
RADIATION HEATER

FIGURE 6 PHOTOGRAPH OF V-10 BLOCK, VALVE
AND REACTION CAPSULE

FIGURE 7 DIAGRAM OF CESIUM DISPENSING SYSTEM

One vial has been submitted to the RCA Lancaster Chemical and Physical Laboratory for spectrographic analysis.

Phase II Material Purification

A study to determine the best method for manufacturing the sintered powder molybdenum reservoir material was completed. The investigation was based on a prior adsorption reservoir study conducted under sponsorship of the AEC under Contract AT(30-1)-3642. The objective of the present study is to develop a less dense adsorbate body which would permit a larger storage surface. To achieve this reduced density, a series of tests were performed by varying the compacting pressure, sintering temperature and sintering atmosphere. The molybdenum powders selected for testing were Wah Chang Plasmamet (-325 mesh), and Phillips Elmet (-400 mesh). Photomicrographs of the evaluated samples, Figures 8 through 14, show that Wah Chang (-325) mesh powder, when compressed at 15 tons per inch² and fired in vacuum at 1800° C, produced the best void structure. In addition, handling capability and scratch hardness were also satisfactory. The density was determined to be 68 percent which is 8 percent less than that developed during the earlier contract. A second sample, produced from a second lot of Wah Chang powder, yielded a 58 percent density under the same vacuum firing conditions.

The surface area contained in the sintered molybdenum powder requires accurate determination for effective reservoir design. A review of the techniques employed by other investigators indicated that two forms of measurements can be used. The first technique uses permeability measurements of gas flow through the porous substrate. This method is outlined in the text "Fine Particle Measurement" by Orr and Dallavalle. Using this method, a measurement system was constructed and values of static pressure head versus flow rate were established. A photograph, Figure 15, shows the parts of the containment and pressure measuring housing used

FIGURE 8 PHOTOMICROGRAPH OF WAH CHANG
PLASMAMET, M200-320 (-325 MESH)
Magnification 138X

Pressing Pressure	15 Tons/Inch ²
Firing Temperature	1600° C
Firing Atmosphere	Wet Hydrogen
Firing Time	30 Minutes
Fired Density	68.42%

FIGURE 9 PHOTOMICROGRAPH CROSS-SECTION
OF WAH CHANG PLASMAMET M200-320
(-325 MESH) Magnification 138X

Pressing Pressure	15 Tons/Inch ²
Firing Temperature	1800° C
Firing Atmosphere	Wet Hydrogen
Firing Time	30 Minutes
Fired Density	68.92%

FIGURE 10 PHOTOMICROGRAPH CROSS-SECTION
OF WAH CHANG PLASMAMET M200-320
(-325 MESH) Magnification 138X

Pressing Pressure	15 Tons/Inch ²
Firing Temperature	1600° C
Firing Atmosphere	Dry Hydrogen
Firing Time	30 Minutes
Fired Density	67.42%

FIGURE 11 PHOTOMICROGRAPH CROSS-SECTION
OF WAH CHANG PLASMAMET M200-320
(-325 MESH) Magnification 138X

Pressing Pressure	15 Tons/Inch ²
Firing Temperature	1800° C
Firing Atmosphere	Dry Hydrogen
Firing Time	30 Minutes
Fired Density	68.88%

FIGURE 12a PHOTOMICROGRAPH CROSS-SECTION
OF WAH CHANG PLASMAMET M200-320
(-325 MESH) Magnification 138X

Pressing Pressure	15 Tons/Inch ²
Firing Temperature	1600° C
Firing Atmosphere	Vacuum
Firing Time	30 Minutes
Fired Density	66.52%

FIGURE 12b PHOTOMICROGRAPH CROSS-SECTION
OF WAH CHANG PLASMAMET M200-320
(-325 MESH) Magnification 552X

FIGURE 13 PHOTOMICROGRAPH CROSS-SECTION
OF WAH CHANG PLASMAMET M200-320
(-325 MESH) Magnification 138X

Pressing Pressure	15 Tons/Inch ²
Firing Temperature	1800° C
Firing Atmosphere	Vacuum
Firing Time	30 Minutes
Fired Density	68.15%

FIGURE 14 PHOTOMICROGRAPH CROSS-SECTION
OF PHILLIPS ELMET (-400 MESH)
Magnification 138X

Pressing Pressure	11 Tons/Inch ²
Firing Temperature	1400° C
Firing Atmosphere	Vacuum
Firing Time	30 Minutes
Fired Density	61.21 %

FIGURE 15 PHOTOGRAPH OF CONTAINMENT VESSEL
PARTS USED FOR SURFACE AREA MEASURE-
MENTS

to support a 1-1/4 inch diameter by 1/8 inch thick sample of Wah Chang (-325) molybdenum powder which was sintered at 1800° C in vacuum. A similar sample of Phillips Elmet (-400) mesh powder was also measured.

A photograph of the permeametry test apparatus is shown in Figure 16. In performing this test, dry nitrogen gas was passed through the sample. The flow rate and pressure loss across the sample were recorded. The values recorded for Wah Chang (-325) at a flow rate of 3.826 cc/second was 4805.7 dynes/cm² static pressure. The values for Phillips Elmet (-400) at 3.826 cc/second flow rate was 33.3 x 10⁴ dynes/cm² static pressure. These values were substituted into the equation given by Orr and Dallavalle for permeametry measurements as follows:

$$V/t = \frac{A \Sigma \Delta P}{k \mu L} \left[\frac{\Sigma^2}{S_v^2 (1 - \Sigma)^2} + \frac{8}{3} \sqrt{\frac{2Rt}{\pi M}} \frac{\delta k_o \mu \Sigma}{p S_v (1 - \Sigma)} \right]$$

where,

S_v	=	surface area per unit volume	cm ² /cm ³
A	=	sample surface impingement area	cm ²
L	=	sample thickness	cm
Σ	=	porosity	--
μ	=	viscosity of fluid	poise
t	=	time	sec
V	=	flow volume	cm ³
R	=	gas constant	
M	=	molecular weight of gas	grams
δ	=	function of meanfree path to capillary	diameter

FIGURE 16 PHOTOGRAPH OF PERMEAMETRY
TEST POSITION

k_o	=	shape factor vs porosity	--
k	=	length aspect factor (4.5 for spheres)	--
P	=	mean pressure	dynes/cm ²
ΔP	=	pressure loss at flow rate	dynes/cm ²

The solution for S_v (surface area per unit volume) is in the form of a quadratic equation. The solution for the real and positive root yields the surface storage value. The value for Wah Chang Plasmamet Molybdenum Spray Powder N200-320 pressed at 15 tons/inch² and vacuum fired at 1800° C was 1.966×10^3 cm² per cm³ of substrate volume.

The second measurement technique uses gas adsorption techniques as outlined by M. J. Katz, Analytical Chemistry, Vol. 26. This measurement is a modification of the standard BET procedure. This procedure, using xenon gas, was recommended by Dr. Jules Levine of the RCA, Princeton Laboratories. In this procedure, a monolayer of gas is absorbed by a sample of molybdenum powder substrate when chilled to liquid nitrogen temperature. A monolayer of xenon gas is formed between 79° and 88° K at a gas pressure between 8×10^{-9} torr and 5×10^{-7} torr. The xenon is completely removed at 114° K. Thus, by forming a monolayer of xenon gas on the substrate at low temperature and recording the gas pressure at room temperature resulting from the absorbed gas, it is possible to relate this pressure to surface area by the following derived equation.

$$A = 54 P \times V \quad \text{cm}^2$$

at 25° C (room temp)

Where,

A	=	total surface area	cm ²
V	=	volume of test vessel	cm ³
P	=	pressure of gas	torr

The derivation of this equation appears in Appendix A. A drawing of the test apparatus used in this measurement, Figure 17, shows the sample containment vessel. The Hoke Bellows vacuum valves and pressure gage are shown in Figure 18. The exhaust system, using a vac-ion and vac-sorb pump, produced a vacuum of 10^{-8} torr. The xenon gas bottle (Lot #514202), gas regulator and micro-flow valve are not shown. The test apparatus was baked to remove water vapor at 300° C for 6 hours with a system pressure of 1.7×10^{-7} torr. The system was cooled and a liquid nitrogen block placed around the containment vessel holding the substrate sample. The sample was maintained at this temperature for 25 minutes at a xenon gas pressure of 8.5×10^{-7} torr. The value of gas pressure rise recorded was 10^{-5} torr. This value was much lower than the anticipated 0.5 torr. A repeat of this procedure, using nitrogen gas in place of xenon, will be performed during the next reporting period.

The planned processing treatment for the remaining parts of the converter include: elimination of acid cleaning, the use of solvent cleaning, and high temperature vacuum treatment. Welding of the converter will be performed in the RCA electron beam welder. Processing of the converter, under vacuum conditions, will include mass spectrometer examination of the exhaust gas products. The "cracking" patterns observed will be matched with known compounds for identification. These procedures will be employed prior to introduction of purified cesium into the converter.

Phase III Thermionic Converter with Adsorption Reservoir

The RCA Cylindrical Converter, Type A-1279, was the basic design selected for the integral adsorption reservoir study. This converter was selected because of the vast experience gained with this device during recent years. The proposed design will generate 175 watts of power at 0.5 volts output with emitter temperature of 1500° C. The design employs an all molybdenum construction except for

FIGURE 17 DRAWING OF GAS ADSORPTION CONTAINMENT VESSEL

FIGURE 18 PHOTOGRAPH OF SAMPLE MATRIX
CONTAINMENT VESSEL

insulating members and suitable braze materials. The molybdenum construction lends itself well to the use of molybdenum matrix reservoir.

A review of potential reservoir locations within the A-1279 converter was initiated. The selected location provided the maximum adsorbate volume and was integral with the converter. The location selected was a concentric annular sleeve 3/8 inch in thickness which surrounded the outer shell of the collector. This location allows 68 cm³ of adsorbate material. The required "active" cesium content, stored on the walls and in the volume of the A-1279 converter, is 2.186×10^{18} atoms (refer to Appendix A). The quantity of cesium atoms stored on the surface of the reservoir material was computed to be 1.9×10^{19} atoms by assuming that a unit surface coverage is present at 650°C and 3 torr. Thus, the reservoir will yield approximately a 10:1 ratio of stored to active cesium atoms.

The design generated for the first model of the integral reservoir converter is shown in the cross-sectional view of Figure 19. The molybdenum powder matrix reservoir is indicated by the cross-hatched lines. Not shown, is a ring of .040 inch diameter holes which extend through the heat shield support and the collector end plates. These holes allow circulation of stored cesium from the matrix reservoir into the emitter-to-collector interspace. A hole was machined through the outer shell, reservoir matrix, and collector to allow optical viewing of the emitter temperature. A sapphire window will be attached to the molybdenum side arm which is welded to the outer shell. The exhaust gases will be removed and the cesium introduced through the cesium still and valve appendage. This appendage is attached to the sapphire window through a stress isolating bellow assembly as shown in Figure 20. The side arm appendage of the cesium still will contain the purified cesium stored in the copper vials as discussed in Phase I. The bakeable Hoke valve, Type 4393V8Y, is interposed between the auxiliary liquid cesium pool and the converter. Remote control operation of this valve is planned

FIGURE 19 CROSS-SECTIONAL DRAWING OF THE MODIFIED RCA A-1279 CONVERTER

FIGURE 20 DRAWING OF PROCESSING VALVE APPENDAGE

after establishing the desired operating conditions in the converter. The thermal source for the converter will be a lithium-TZM heat pipe as shown in Figure 21. This design is similar to successful models previously built and tested by RCA. A matching taper section on the heat pipe will mate with a similar counter taper located on the inside of the converter collector.

Fabrication of parts for the modified A-1279 converter and companion heat pipe were completed and are shown in Figures 22 and 23. The cesium still and valve arrangement appendage have also been fabricated. Photographs of these assemblies are shown in Figures 24 and 25. The molybdenum matrix reservoir was formed as previously described in Phase II. A set of hardened steel pressing dies were also completed. The dies were used to press the molybdenum matrix reservoir in the "green" state. A pressing plug was precision fit between the concentric molybdenum cylinders to act as a ram for compacting the powder. A tapped sleeve, utilizing 3 screws, was used to withdraw the ram after compressing partial fills of powder. The tooling was designed to permit pressing from both ends. This procedure was employed to achieve a more uniform density of pressed powder. The material used was Wah Chang Corp. Plasmamet 200-320, Lot No. MO-SP-12 (-325 mesh) molybdenum powder. A pressure of 12 tons/in^2 was applied to the surface of the powder (78,000 lbs total force). The reservoir sub-assembly, in its "green" pressed condition, is shown in photograph Figure 26. This assembly was fired at 1800°C for thirty minutes at a pressure of 5×10^{-6} torr. The rate of temperature rise was 200°C/hour to prevent any large thermal gradient in the sub-assembly. A photograph of the sub-assembly, taken after vacuum sintering, appears in Figure 27. Detail machining was then performed to accommodate electron beam welding of the various flanges to be attached. The entire pressing process was performed without the use of any lubricants to prevent contamination of the formed matrix.

FIGURE 21 DRAWING OF THERMAL SOURCE HEAT PIPE

FIGURE 22 PHOTOGRAPH OF MODIFIED A-1279
CONVERTER PARTS

FIGURE 23 PHOTOGRAPH OF MODIFIED HEAT PIPE
PARTS

FIGURE 24 PHOTOGRAPH OF CESIUM STILL

FIGURE 25 PHOTOGRAPH OF VALVE APPENDAGE

FIGURE 26 PHOTOGRAPH OF RESERVOIR SUB-ASSEMBLY
IN "GREEN" PRESSED CONDITION

FIGURE 27 PHOTOGRAPH OF RESERVOIR SUB-ASSEMBLY
AFTER VACUUM FIRING

During the remaining months of the program, the modified matrix converter will be assembled, processed and evaluated to establish integral cesium reservoir operation.

APPENDIX A

DERAVATIONS AND COMPUTATIONS

A. Determination of Surface Area From Adsorbed Gas Layer

Using a method for surface area measurement as outlined by M. T. Katz*

Surface Area (S) equals,

$$S = \frac{C-1}{NmC} \approx \frac{1}{Nm} \quad \text{if } C \gg 1$$

Where C is a constant defined by the equation

$$E_1 - E_2 \approx RT \log C$$

E_1 = heat of adsorption of first adsorbed layer

E_2 = heat of liquification of the adsorbing gas

R = gas constant

T = absolute temperature

If a monolayer is formed $C \gg 1$ and

$C-1/C \approx 1$ then,

$$S = \frac{C-1}{NmC} \approx \frac{1}{Nm}$$

Where, Nm = number of moles needed to form a monolayer

P_o = measurement pressure of gas

P_2 = equilibrium pressure of monolayer formation

N_a = number of moles of gas adsorbed per gram of adsorbent

*M. J. Katz, Analytical Chemistry, Vol. 26

then,

$$Nm = \frac{1}{S} = \frac{P_2/P_o}{P_2/N_a (P_o - P_2)} = \frac{N_a (P_o - P_2)}{P_o}$$

If $P_o \gg P_2$ at $78^\circ K$ a monolayer of xenon is formed at 9×10^{-9} to 5×10^{-7} torr pressure

then, $Nm \approx N_a$

The number of xenon atoms stored per unit surface area are

$$\sigma_{\max} = N/A = \frac{1}{2\sqrt{3}} \frac{1}{R^2} \quad \text{where } R = 2.20 \text{ \AA} \text{ for xenon (Van Der Waals' Radius)}$$

thus,

$$\sigma_{\max} = \frac{1}{2\sqrt{3}} \times \frac{1}{(2.20)^2 \times 10^{-16}} = 5.95 \times 10^{14} \text{ atoms/cm}^2$$

Assuming $P_o \gg P_2$ at T_o then, since

$$PV = NRT = \frac{g}{m} RT$$

(Density of xenon)

where,

$$P_o = 1 \text{ torr}, V = 1 \text{ cm}^3 \text{ (unit volume)} T = 300^\circ K, M = 131.1 \text{ grams-moles}$$

$$g/v = 6.983 \times 10^{-6} \text{ grams/cm}^3$$

$$n = \frac{g}{m} = 5.318 \times 10^{-8} \text{ moles}$$

$$\text{Using Avogadro's Number} = 6.03 \times 10^{23} \frac{\text{molecules}}{\text{gram-mole}}$$

The gas density equals,

$$\rho = \frac{9.62 \times 10^{18}}{T} \times P \text{ (torr)} \frac{\text{Molecules}}{\text{cm}^3}$$

thus,

$$P \times \frac{9.62 \times 10^{18}}{300} = \frac{5.95 \times 10^{14}}{V} \times A$$

$$A = \frac{9.62 \times 10^{18}}{(300) (5.95 \times 10^{14})} \times P(\text{torr}) V (\text{cm}^3)$$

and surface area equals,

$$A(\text{cm}^2) = 54 P (\text{torr}) V (\text{cm}^3)$$

B. Computation of "Active" Cesium Atoms Stored in Converter

1. Estimates of Internal Surface Area of A-1279

a. Emitter	92.25 cm ²
b. Collector	51.64 cm ²
c. Emitter Plate	15.63 cm ²
d. Collector Weld Ring and Plate	19.77 cm ²
e. Insulator Assemblies	36.07 cm ²
f. Expansion Ring	15.46 cm ²
g. Bellows	26.16 cm ²
h. Window Pipe	13.92 cm ²
i. Matrix Retainer	54.3 cm ²

$$S_A = \text{Total Surface} = 325.2 \text{ cm}^2$$

2. Total Surface Area less Emitter Area

$$S'_A = 325.2 - 92.25 = 233 \text{ cm}^2$$

The number of atoms of cesium stored in a monolayer per unit surface is $\sigma = 4.8 \times 10^{14}$ atoms/cm²* with $\theta_1 = 1$ at 923°K and pressure = 2 torr

3. Cesium Atoms Stored on Emitter

Assuming $\phi = 2.6$ ev work function of Cs on Mo at 1500° C

from curves $\theta = .1$ coverage fraction

then,

$$\begin{aligned} N_S &= \sigma \theta_1 A_1 + \sigma \theta_2 A_2 \\ &= (4.8 \times 10^{14}) (1) (233) + (4.8 \times 10^{14}) (.1) (92.25) \\ &= 1.162 \times 10^{17} \text{ atoms of cesium on surfaces} \end{aligned}$$

4. Cesium Stored in Volume of Converter

a. Converter Sheath	1.028 cm ³
b. End Supports (emitter end)	13.04 cm ³
c. End Supports (collector end)	18.04 cm ³
d. Window Pipe	2.199 cm ³

$$\text{Total Volume} = 34.36 \text{ cm}^3$$

At 3 mm of Hg and 590°K Cs reservoir temperature

$$N_{cs} = 6 \times 10^{16} \text{ atoms/cm}^3 **$$

*J. Levin, RCA Review, March, 1966, p. 43.

**J. M. Huston, Advances in Electronics Vol. 17, 1962.

Thus, stored volume = $34.36 \times 6 \times 10^{16} = 20.6 \times 10^{17}$ atoms

5. Total Number of Active Cesium Atoms in Converter

$$N_{cs} = N_v + N_s = 20.6 \times 10^{17} + 1.162 \times 10^{17} = 2.186 \times 10^{18} \text{ atoms}$$

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