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

**TOPICAL REPORT
FOR
TASK II
"DEVELOPMENT OF ADSORPTION RESERVOIR"
AUTHOR - R. A. FREGGENS**

**PERIOD OF PERFORMANCE
MARCH 1, 1969 THROUGH SEPTEMBER 30, 1969**

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

**BY
RCA CORPORATION
ELECTRONIC COMPONENTS
LANCASTER, PENNSYLVANIA**

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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 was monitored by Mr. Lester Price of the Space Nuclear Systems Division, Germantown, Maryland.

This Topical Report covers the work performed from 1 March 1969 through 30 September 1969. The studies and accomplishments presented herein represent 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 integral adsorption reservoir thermionic converter. Three general areas were investigated during the study. They 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 also 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 modified to include an integral matrix reservoir and designated the RCA A-1345. The modified design included 80 cm³ of reservoir matrix integrally located within the converter. The device was fabricated, processed and electrically life tested using its own internal cesium reservoir for a period of 380 hours before the heat pipe-heat source failed forcing termination of the test.

Long term changes in electrical output were observed after installation of each new heat source which confirmed the slowly changing nature of internal cesium equilibrium. The ability of the converter to operate successfully and stabilize at a new satisfactory level of performance after each thermal cycle validates the fundamental design.

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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 preceding U. S. Atomic Energy Commission Contract AT(30-1)-3642, which authorized the feasibility study of a cesium adsorption reservoir converter, a loss of performance was encountered which appeared to be associated with cesium purity and converter materials. A three phase study program, Task II, was authorized to investigate these problems.

Phase I of the new program, Cesium Purification, was reported on in detail in the First Topical Report, No. NYO3979-2. In brief summary, the formation of a tertiary Ba Cs CL compound with Ba metal was accomplished at high temperature and under high vacuum. Subsequent distillation freed the unreacted cesium and dispensed it into copper vials suitable for converter processing. Chemical analysis confirmed the virtual absence of any halides in the purified cesium. Prior chemical analysis of cesium used in thermionic converters normally did not attempt to determine the presence of halides but rather, metallic impurities. The formation of Cs CL compounds were held responsible for the poor operating life encountered during the earlier contract.

Phase II of the program, Material Purification, was partially reported on in the First Topical Report, No. NYO3979-2. A study of factors involved in formation of a large storage area molybdenum matrix was completed. The final matrix selected used fine (-325 mesh) molybdenum powder, high pressure,

(15 tons/in²) and a high vacuum (5×10^{-5} torr) sinter (1800° C). No foreign materials were introduced during the formation procedure. A chart detailing the cleaning processes used on each part and assembly is included herein as Appendix B. To check the cleaning procedures used, samples of the exhaust gas products were analyzed with a Veeco Mass Spectrometer. The evolving gasses were scanned at periodic intervals during converter "outgassing". Mass to charge ratios of 37 or 38 were not detected. Thus, no chloride compounds were retained as a result of the cleaning procedures employed.

Phase III of the program, Converter with Adsorption Reservoir, was completed by the fabrication and evaluation of the A1345 which is a cylindrical thermionic converter containing an integral molybdenum matrix reservoir. The basic design was discussed in the First Topical Report, No. NYO3979-2. The design used the RCA-1279 Cylindrical Converter Configuration which was modified to include a concentric shell of sintered molybdenum powder concentric with and attached to the outside of the collector. The storage volume of this internal reservoir was 446 milligrams of cesium yielding a 925 to 1 stored to active cesium atom ratio. The converter operating conditions were established by dynamic operation and a separation valve closed by remote control. A series of coil tungsten heaters were used as the thermal source until the converter was mounted on the lithium-TZM heat pipe. Life test attained a value of 378 hours before termination of testing. Failure of a heat pipe weld caused the termination of the life test although the converter was still operable.

The following conclusions were reached following completion of the program. First, halogens can be removed from cesium; Second, a large surface to volume ($5.27 \times 10^4 \text{ cm}^2/\text{cm}^3$) molybdenum matrix can be formed; Third, a suitable processing program has been developed which does not introduce contamination and Fourth, a high power (200 watt) integral reservoir thermionic converter can be fabricated and operated for hundreds of hours.

SECTION II

PROGRAM ACCOMPLISHMENTS

Phase I - Cesium Purification

The process selected to remove halide impurities from cesium was described in the First Topical Report No. NYO3979-2. The procedure used to create a chemical reaction forming a tertiary halide compound with cesium and barium metal was described.

A cesium sample, which was subjected to the purification cycle described in the First Topical Report, was analyzed by the RCA Lancaster Chemical and Physical Laboratory. The values of the contaminants found appear in Table I, page 4. The virtual absence of chlorine, fluorine or barium in this sample is noteworthy. This verifies the fact that the process used to form the tertiary compound of cesium, barium and chlorine was successful. The newly formed compound did not co-distill with the free cesium when the copper vials were filled. This series of events was anticipated by the purification plan.

Phase II - Material Purification

During this report period, additional measurements of the reservoir material surface area were made. Surface adsorption by the matrix was evaluated using both xenon and nitrogen gas.

Each gas was individually adsorbed on a sample of sintered molybdenum matrix after thorough exhaust and removal of extraneous gases by cooling the sample to liquid nitrogen temperature (78°K). The excess measurement gas stored in the sample and containment vessel was then evacuated. The sample and containment vessel were allowed to rise to room temperature (300°K) and the accompanying pressure rise recorded on the pressure gages attached to the containment

TABLE I
CESIUM ANALYSIS

(All results are expressed in parts per million by weight)

<u>Chemical Analysis</u>	
Chlorine	6 PPM
<u>Atomic Adsorption Analysis</u>	
Sodium	1 PPM
Potassium	46 PPM
Rubidium	214 PPM
<u>Emission Spectrography</u>	
Aluminum	500 PPM
Barium	None Detected
Calcium	>50 PPM
Chromium	>50 PPM
* Copper	35000 PPM
Iron	400 PPM
Magnesium	200 PPM
Nickel	>50 PPM
Silicon	>50 PPM

* Copper vials were used for storage and transport of cesium and are the probable cause of contamination

vessel (Refer to Figure 17 of First Topical Report). The pressure recorded was related to the surface area of the matrix by the expression developed by Dr. Levine and reported in the First Topical Report. The value computed for surface area using xenon gas was $.0966 \text{ cm}^2/\text{cm}^3$ of matrix material. This value is considerably less than the anticipated value. The measurement procedure was repeated using nitrogen. The equation relating surface area to pressure rise for nitrogen was derived and is expressed as follows:

Surface area equals,

$$A = 174 PV \quad (\text{cm}^2)$$

Where,

A = total surface area (cm^2)

P = pressure of gas (torr)

V = volume of test vessel (cm^3)

The value determined using nitrogen was $3.96 \times 10^2 \text{ cm}^2/\text{cm}^3$ of matrix material. This value is more probable than the xenon value computed, however, it is only (0.2) two-tenths of the value determined and reported earlier by permeametry measurements. The variation in measured values is primarily due to the inability to attain a monolayer coverage by the gas as required when deriving the pressure surface area relationship. The surface adsorption isotherm phenomena must be further investigated before accurate values of surface area may be determined in this fashion.

Since the surface area measurements were believed to be inaccurate using the modified BET¹ procedure, a sample of the molybdenum matrix was supplied to Skinner & Sherman Inc. of Newton, Massachusetts for measurement using a standard BET analysis.

¹Brunauer, S., Emmett, P. H., and Teller, E., "The Adsorption of Gases in Multimolecular Layers", J. Am. Chemical Society. 60, 309-16, 1938.

The sample of sintered molybdenum supplied for measurement was formed from Wah Chang Plasmamet (-325 mesh) powder, pressed at 12 tons/in² and fired in vacuum at 1800°C. The sintered density was 57.5% of theoretical density (10.2 gm/cm²). The surface area determined by Skinner & Sherman was 0.89 m²/gram. Argon gas was used in the measurement because the sample volume was small. Relating this value to the sample weight (16.761 grams) and volume (2.829 cm³) the storage area per unit volume is 5.272×10^4 cm²/cm³. Thus, the storage ability of 80 cm³ contained in the integral reservoir is 446 milligrams, assuming a unity value of isotherm. (See Appendix A). The latter measurement indicates a greater surface area than either measurement by gas permeametry or modified BET procedures. The increase is by a factor of 26.8 times the permeametry measurement and 133.2 times the modified BET procedure value. The value determined by Skinner & Sherman has a reported accuracy of 5% while the accuracy of the other measurements is unknown. Therefore, the surface area used for cesium storage was based on the Skinner & Sherman measurement.

The processing applied to the converter parts is presented in tabular form in Appendix B. The primary feature of this processing sequence is the absence of chemical cleaning by acids. Instead, the parts were subjected to organic solvents and ultrasonic washing. The final procedure before assembly or electron beam welding was a high vacuum, high temperature firing of the part.

All welds were made with an electron beam welder operating at a vacuum pressure of 10^{-6} torr. The final nickel-palladium braze of the side arm to the valve appendage, shown in Figure 1, was completed in a dry hydrogen atmosphere using radio frequency heating.

FIGURE 1 CONVERTER AND SIDE ARM APPENDAGE

To evaluate the effectiveness of the converter parts cleaning and fabrication procedures, the exhaust system was provided with a Veeco Mass Spectrometer, Type GA-3. The Spectrometer was attached to the vacuum processing position through a valve arrangement which allowed sampling of the exhaust gas products during converter processing. A series of 17 scans were recorded during the converter exhaust cycle. Five of these scans are shown as Figure 2 through 6. Correlation of the scan number with the stage of converter exhaust can be made from Table II.

A "blank" run to establish initial conditions was made before heating the converter. At subsequent thermal processing stages, a continuous sweep of mass to charge ratios (from 90 to 2) were made and may be compared with the preceding scans. The "cracking pattern" for acetone (Figure 7) was evident during the early stages of processing and accounted for the very large gas pressure observed. An important observation was the total absence of masses between 43 to 32. This condition indicates that no chlorine or hydrogen chloride (mass No. 37 & 38) were present during any phase of the vacuum processing.

The major residual gases evolving from the converter after the 102 hour processing cycle and cesium insertion are indicated in scan No. 17. The major mass to charge numbers indicate water vapor (19, 18, 17); carbon monoxide, (28, 22, 12); oxygen (32, 16); nitrogen (28, 14); hydrogen (2); and a small amount of argon (40, 20) were present at the termination of processing.

Phase III - Thermionic Converter with Adsorption Reservoir

The design of the integral reservoir thermionic converter was discussed in the First Topical Report, No. NYO3979-2. The cesium storage reservoir was accomplished by using sintered molybdenum powder attached to and concentric with the collector. The new converter was designated the RCA-A1345 and is shown in the cross-section drawing of Figure 8. The dimensions of the device and the materials used are listed in Table III.

FIGURE 2 SPECTROGRAPHIC MASS-TO-CHARGE SCAN NO. 1

FIGURE 3 SPECTROGRAPHIC MASS-TO-CHARGE SCAN NO. 2

FIGURE 4 SPECTROGRAPHIC MASS-TO-CHARGE NO. 10

FIGURE 5 SPECTROGRAPHIC MASS-TO-CHARGE NO. 15

TABLE II
A-1345 CONVERTER PROCESSING SUMMARY

Minutes	Heater			T _E °C	T _E Corr. °C	T ₁ °C	T ₂ °C	T ₃ °C	T ₄ °C	T ₅ °C	T ₆ °C	T ₇ °C	T ₈ °C	T ₉ °C	T ₁₀ °C	T ₁₁ °C	T ₁₂ °C	T ₁₃ °C	T ₁₄ °C	Converter Vac Ion Press Torr	Vacuum Bell Press Torr	Spectrometer Vac Ion Press Torr	Spectrometer Chamber Torr	Spectrometer Port Position	Scan	
	E Volt	I Amp.	P Watts																							
0	0	0	0	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	25	2.5 x 10 ⁻⁷	1.9 x 10 ⁻⁷	6.0 x 10 ⁻⁷	1.1 x 10 ⁻⁶	Closed	--	
37	0	0	0	25	25	25	25	25	25	25	25	105	105	100	25	25	90	25	25	6.0 x 10 ⁻⁶	2.5 x 10 ⁻⁷	6.0 x 10 ⁻⁸	8.0 x 10 ⁻⁷	Open	1	
145	4.0	24	96	--	--	25	25	25	25	25	25	230	234	225	25	25	190	25	25	1.0 x 10 ⁻⁵	6.1 x 10 ⁻⁷	4.5 x 10 ⁻⁸	4.0 x 10 ⁻⁷	Open	2	
305	6.1	29	177	780	--	95	90	132	90	85	100	440	445	404	134	139	355	174	192	8.0 x 10 ⁻⁵	2.5 x 10 ⁻⁶	2.5 x 10 ⁻⁸	6.0 x 10 ⁻⁷	Open	3	
1300	7.4	32	237	860	--	150	170	230	199	182	226	495	500	464	276	485	422	235	255	1.5 x 10 ⁻⁵	7.6 x 10 ⁻⁶	3.0 x 10 ⁻⁸	5.0 x 10 ⁻⁷	Open	4	
1470	7.8	33	257	905	--	210	260	275	265	252	285	508	515	475	346	370	435	289	305	2.5 x 10 ⁻⁵	5.9 x 10 ⁻⁶	3.5 x 10 ⁻⁸	4.6 x 10 ⁻⁷	Open	5	
1745	9.6	38	365	1010	--	255	289	312	292	290	337	570	581	506	404	435	480	310	337	2.5 x 10 ⁻⁵	7.0 x 10 ⁻⁶	4.0 x 10 ⁻⁸	4.8 x 10 ⁻⁷	Open	6	
1810	10.4	40	416	1025	--	290	290	360	295	355	395	615	620	530	451	490	510	341	370	2.5 x 10 ⁻⁷	7.6 x 10 ⁻⁶	4.5 x 10 ⁻⁸	6.1 x 10 ⁻⁷	Open	7	
2745	11.8	43	507	1110	--	324	365	410	385	406	425	625	652	526	468	510	522	382	424	8.5 x 10 ⁻⁶	3.2 x 10 ⁻⁷	3.0 x 10 ⁻⁸	5.5 x 10 ⁻⁷	Open	8	
2925	13.2	46	607	1150	--	425	455	437	459	460	457	682	693	552	472	516	531	387	435	1.0 x 10 ⁻⁵	5.8 x 10 ⁻⁶	4.0 x 10 ⁻⁸	5.4 x 10 ⁻⁷	Open	9	
3095	15.2	50	760	1232	1391	428	462	439	462	466	457	727	739	561	469	513	542	390	441	1.0 x 10 ⁻⁵	5.7 x 10 ⁻⁶	4.0 x 10 ⁻⁸	5.3 x 10 ⁻⁷	Open	10	
3205	17.6	54	950	1308	1484	453	463	439	460	457	453	785	799	551	459	501	554	390	442	8.0 x 10 ⁻⁶	5.5 x 10 ⁻⁶	3.5 x 10 ⁻⁸	4.4 x 10 ⁻⁷	Open	11	
4195	17.3	54	950	1300	1474	626	487	438	470	476	455	781	795	558	456	507	556	389	454	7.5 x 10 ⁻⁷	2.5 x 10 ⁻⁶	3.5 x 10 ⁻⁸	4.5 x 10 ⁻⁷	Open	12	
4225	17.3	54	950	1300	1474	626	487	438	470	476	455	781	795	558	456	507	556	389	454	7.5 x 10 ⁻⁷	2.5 x 10 ⁻⁶	3.5 x 10 ⁻⁸	4.5 x 10 ⁻⁷	Closed	13	
4465	17.5	54	945	1300	1474	618	480	430	464	467	450	778	792	554	449	500	553	379	446	5.5 x 10 ⁻⁷	2.1 x 10 ⁻⁶	3.5 x 10 ⁻⁸	3.5 x 10 ⁻⁷	Open	14	
4645	17.8	55	979	1313	1490	626	486	434	469	473	455	786	802	559	454	504	559	384	452	6.0 x 10 ⁻⁷	2.1 x 10 ⁻⁶	3.0 x 10 ⁻⁸	2.7 x 10 ⁻⁷	Open	15	
6075 (101 Hrs.) CESIUM CAPSULE OPENED - CESIUM THERMALLY TRANSFERED INTO AUXILIARY RESERVOIR AND CONVERTER																										
6350 CONVERTER OPERATION IN "ARC MODE" AT 0.63 VOLTS AND 111 AMPERES D. C. POWER OUTPUT																										
6350	22.5	64	1440	1330	1510	499	474	359	384	331	273	613	608	639	22	523	514	328	388	2.0 x 10 ⁻⁷	2.3 x 10 ⁻⁶	3.0 x 10 ⁻⁸	2.8 x 10 ⁻⁷	Closed	16	
6355	22.5	64	1440	1330	1510	499	474	359	384	331	273	613	608	639	22	523	514	328	388	2.0 x 10 ⁻⁷	2.3 x 10 ⁻⁶	4.5 x 10 ⁻⁸	6.0 x 10 ⁻⁷	Open	17	
6450 (107.5 Hrs.) CONVERTER & CESIUM STILL COOLED - "PINCH-OFF" OF CESIUM STILL ACCOMPLISHED

FIGURE 7 SCAN SHOWING THE "CRACKING PATTERN"
 FOR ACETONE

FIGURE 8 CROSS-SECTIONAL DRAWING OF THE RCA-A-1345 CONVERTER

TABLE III A-1345 THERMIONIC CONVERTER DIMENSIONS AND MATERIALS

<u>Dimension</u>	<u>Value</u>
A	4.030
B	3.500
C	2.995
D	2.475
E	2.075
F	2.300
G	2.500
H	1.115
I	.400
*J	.9915
Spacing E-C	.008
Cathode Area	7.844 in ²

* 1° Tapper

Note: All Dimensions in Inches

<u>Part</u>	<u>Material</u>
Collector	Vacuum Arc Cast Moly. Bar
Emitter	Vacuum Arc Cast Moly. Bar
Collector Terminal	Vacuum Arc Cast Moly. Sheet
Expansion Bellows	Vacuum Arc Cast Moly. Sheet
Emitter Terminal	Vacuum Arc Cast Moly. Sheet
Heat Shields	.001 Thick Moly Sheet
Moly. Matrix Res.	(-325) Mesh Moly Powder
Insulator	Diamonite 94.7% Al ₂ O ₃
Isolation Ring	Vacuum Arc Cast Moly. Sheet
Window View Pipe	Vacuum Arc Cast Moly. Bar
Window	Sapphire
Braze	100% Copper

The assembled converter and side appendage containing the pumping arm, auxiliary cesium reservoir, and separation valve appears in Figure 1. A cross-sectional drawing of the side appendage appears as Figure 20 in the First Topical Report. The auxiliary liquid cesium pool used for optimization of the cesium pressure and the high temperature separation valve were also described. The assembly was attached to the cesium still which contained two capsules of purified cesium produced during Phase I. This assembly, in turn, was attached to a vac-ion pump through a pipe and bellows assembly. A photograph of the entire processing assembly and insulated nichrome heaters, which were wrapped about the piping sections, is shown in Figure 9.

Figure 10 shows the location of the nichrome heater, chill blocks, and thermocouple positions used during the "degassing" phase of the exhaust procedure. A tabular summary of the processing is presented in Table II. The temperature profile of the thermionic converter, cesium still and appendage piping is indicated at each point in time. The state-of-vacuum for both the converter, vacuum bell and mass spectrometer is indicated in the same time-temperature relation. The mass spectrometer scan taken at each reference point was also recorded.

The converter was processed under vacuum for a period of 101 hours before introduction of cesium. Included in this processing was a 25 hour period when the entire converter was operated at 1073°K. The reduction in gas pressure to 10^{-7} torr while operating at this temperature level validates the cleaning procedures used.

After completion of the "degassing" phase, the cesium capsules were broken and the cesium thermally distilled into the auxiliary liquid reservoir and converter. The converter was operated in the "arc mode" yielding 0.63 volts

FIGURE 9 PHOTOGRAPH OF PROCESSING ASSEMBLY

FIGURE 10 DRAWING OF THERMOCOUPLE, CHILL BLOCK AND HEATER LOCATION

at 111 amperes of electrical output. After confirming that the converter was electrically operable, a nickel "pinch-off" was made in the pipe leading to the cesium still and vac-ion pump at 107.5 hours of processing. After separation of the converter and its side appendage from the vacuum system, the auxiliary liquid reservoir was operated at approximately 558°K with the emitter at 1773°K and the collector at 853°K. The valve between the liquid reservoir and the converter was repeatedly opened to allow an interchange of cesium while attempting to obtain a maximum value of converter output voltage and current. The valve was opened and closed by use of the remote rotary shaft mechanism inserted through the vacuum bell plate. In this manner, desirable conditions in the converter could be established while under dynamic operation. A maximum steady state converter performance was obtained after approximately 16 hours of stabilization. The following maximum steady state conditions were established. The thermocouple locations for this test data are shown in Figure 11.

Optimum Conditions for Steady State Operation

Emitter temperature*	$T_{E \text{ CORR}}$	=	1773° K
Cesium reservoir temperature	T_{CS}	=	577° K
Collector temperature	T_C	=	860° K
Valve temperature	T_{VALVE}	=	736° K
Bellows temperature	$T_{BELLOWS}$	=	924° K
Window temperature	T_{WINDOW}	=	915° K
Convertor output voltage	E	=	.452 Volt
Convertor output current	I	=	224 Amperes
Convertor output power	P	=	101.2 Watts
Emitter current density	J	=	4.43 Amps/Cm ²

* Measurement made by Optical Pyrometer "Mikro-Pyrometer" No. 2773, Pyro-Werk GmbH, Hannover, Germany

FIGURE 11 OPERATING CONVERTER AND VALVE APPENDAGE THERMOCOUPLE LOCATIONS

In addition, the converter performance was recorded at (T_E) emitter temperatures of 1723° and 1773° K. The internal reservoir temperature was simultaneously varied between 563° K and 583° K. The electrical output results for these various combinations of temperatures are shown in Table IV and are plotted in Figure 12. Values for converter efficiency were not determined since no measure of extraneous thermal loss was attempted.

The converter was then evaluated by applying an AC voltage across the electrodes. The circuit diagram is shown in Figure 13. The resultant current versus voltage characteristics of the converter were displayed on an oscilloscope and photographed. AC sweep displays of the characteristics (E vs I) at various auxiliary reservoir temperatures were recorded and are presented as Figures 14 through 18. Table V lists the conditions under which the displays were taken. Figure 11 indicates the location of the thermocouples during this test and the subsequent AC sweep life test.

The converter was established at the optimum condition listed in Table V. The valve between the converter and auxiliary reservoir was then closed. Life test of the converter, operating on the internal reservoir, was initiated. AC sweep displays of the converter characteristic were recorded at the start of life test and at various time intervals. Photographs of these AC sweeps (E vs I) of the converter are shown in Figures 19 through 27. Table VI contains the temperature profile of the converter and its associated appendage for each sweep condition. The major consideration during test was that the operation of the valve, bellows and window side arm was maintained at a temperature above the optimum cesium pool temperature thereby insuring that no secondary cesium pool existed. The reservoir matrix material was operated between 775° and 860° K which provided a unit isotherm value of cesium storage².

² "Adsorption-Type Reservoir for Gas Tubes", K. G. Hernqvist and J. D. Levine, RCA Review, March 1966, Volume XXVII, No. 1, page 144.

TABLE IV DC ELECTRICAL OUTPUT OF CONVERTER

E	Heater		T_E	T_E Corr.	T_1	T_2	T_3	T_4	T_5	T_6	T_7	Conv. Output		
	I	P										E	I	P
Volt	Amp.	Watt	°C	°C	°C	°C	°C	°C	°C	°C	°C	Volt	Amp.	Watt
25.4	67	1701	1320	1498	403	302	463	651	642	593	582	.452	224	101.2
22.8	63	1436	1280	1450	396	290	457	638	636	574	560	.410	172	70.5
22.5	63	1417	1320	1498	393	293	456	640	638	572	561	.502	172	85.8
21.0	60	1260	1280	1450	374	278	482	619	616	561	545	.478	117	55.9
21.9	62	1357	1315	1492	375	279	478	617	613	552	535	.592	100	59.2
20.5	60	1230	1281	1452	376	279	479	609	608	528	513	.520	78	40.6
24.8	65	1612	1330	1510	408	285	519	666	654	602	584	.486	190	92.3
24.5	65	1592	1321	1499	399	288	512	656	648	591	575	.475	187	88.8

FIGURE 12 POWER OUTPUT VERSUS CESIUM TEMPERATURE
WITH LIQUID CESIUM RESERVOIR-RCA A-1345

Equipment

- A. Heat Pipe Power Supply
Nothelfer Winding Labs #17650, 0-4000 Amperes, 0-10 Volts AC
- B. Tektronix Type 536 Oscilloscope
 1. Plug-in Unit Type G Horizontal
 2. Plug-in Unit Type 1A6 Vertical
- C. A. C. Power Supply Nobs 84823
0-500 Amperes, 0-8.0 Volts #9101600141
(Electrically Isolated)
- D. Load
Water Cooled Stainless Steel Tubing & Adjustable Current Clamps
- E. Camera
Tektronic Oscilloscope Camera Type C-12

FIGURE 13 A-1345 CONVERTER LIFE TEST CIRCUIT

FIGURE 14 DISPLAY #1

FIGURE 15 DISPLAY #2

FIGURE 16 DISPLAY #3

FIGURE 17 DISPLAY #5

FIGURE 18 DISPLAY #6

TABLE V CONVERTER OPERATION UNDER VARIED CONDITIONS

Display Number	Heater			T _E	T _E	T ₁	T ₂	T ₃	T ₄	T ₅	T ₆	T ₇	A. C. Sweep	
	E	I	P	Corr.									E Avg.	I Avg.
	Volt	Amp.	Watts	°C	°C	°C	°C	°C	°C	°C	°C	°C	Volt	Amp.
1	22.0	61	1342	1320	1498	406	300	518	656	655	580	555	1.32	106
2	22.0	61	1342	1320	1498	405	290	518	656	655	582	554	--	102
3	22.8	62	1413	1319	1497	410	310	519	663	658	596	571	--	109
4	22.2	61	1354	1321	1499	408	290	520	663	659	590	574	--	105*
5	22.2	61	1354	1321	1499	408	290	520	663	659	590	574	--	105*
6	22.2	61	1354	1321	1499	408	290	520	663	656	590	574	--	105*

* In-line Valve Closed

FIGURE 19 DISPLAY #7

FIGURE 20 DISPLAY #8

FIGURE 21 DISPLAY #10

FIGURE 22 DISPLAY #12

FIGURE 23 DISPLAY #16

FIGURE 24 DISPLAY #17

FIGURE 25 DISPLAY #19

FIGURE 26 DISPLAY #20

FIGURE 27 DISPLAY #25

TABLE VI CONVERTER LIFE TEST CONDITIONS

Display Number	Life Hours	Heater			T _E °C	T _E Corr. °C	T ₁ °C	T ₂ °C	T ₃ °C	T ₄ °C	T ₅ °C	T ₆ °C	T ₇ °C	A. C. Sweep	
		E	I	P										E _{Avg} Volt	I _{Avg} Amp.
7	0	22.5	61	1372	1320	1498	386	304	484	633	643	582	558	1.30	104
8	24	22.5	61	1372	1319	1497	387	304	485	631	647	580	554	1.30	102
9	48	22.5	61	1372	1321	1499	388	304	487	633	644	583	556	1.32	103
10	48.5	22.5	61	1372	1320	1498	414	366	485	632	642	580	553	1.32	103
11	100	23.2	64	1484	1312	1488	330	334	370	513	575	570	526	1.16	104 *
12	103	23.2	64	1484	1312	1488	372	380	397	540	610	610	538	1.16	103
13	120	23.8	62	1475	1305	1480	366	373	389	531	603	575	522	1.16	103
14	126	23.5	62	1475	1308	1485	415	425	440	559	601	559	515	1.16	103
15	144	23.8	62	1475	1305	1480	420	433	450	559	610	562	518	1.20	106
16	168	23.8	62	1475	1293	1465	419	432	451	556	607	556	511	1.24	108
17	181	23.8	63	1499	1315	1492	346	355	413	538	611	558	523	1.24	106*
18	197	23.3	63	1499	1312	1490	376	387	400	528	612	538	507	1.25	106
19	221	23.4	63	1499	1312	1490	376	385	400	526	605	538	502	1.29	110
--	243	2.7	3390	9153	1281	1451	308	---	316	451	557	475	495	---	---
--	246	3.4	3450	11730	1295	1468	392	---	389	540	575	550	566	1.13	105

Δ
Heat
Pipe
1515

(Continued)

TABLE VI CONVERTER LIFE TEST CONDITIONS (Contd.)

Display Number	Life Hours	Heater			T_E	T_E	T_1	T_2	T_3	T_4	T_5	T_6	T_7	A. C. Sweep		
		E	I	P	°C	Corr. °C	°C	°C	°C	°C	°C	°C	°C	E_{Avg} Volt	I_{Avg} Amp.	
20	264	3.4	3360	11424	1307	1483	407	---	407	563	596	580	---	1.17	106	1541
21	280	3.39	3330	11288	1290	1462	406	---	409	558	588	576	---	1.10	101	1520
22	(Not Recorded)															
23	351	3.4	3350	11390	1262	1433	352	---	365	540	602	580	---	1.12	102	1465
24	354	3.4	3390	11526	1286	1457	322	---	332	520	538	573	---	1.12	101	1525
25	370	3.43	3400	11662	1285	1456	326	---	334	524	538	584	---	1.0	99.0	1535
26	378	3.55	3450	12247	1308	1484	335	---	342	540	550	610	---	1.15	103	1570

 Δ Temperature °C

During the 378 hours of operational life, the converter was operated with four different heat sources. The initial heat source was a doubly concentric wound tungsten coil. The converter was heated by radiation from the coils. However, this required a high operating temperature on the coils and caused premature failure because of "sagging" and crystal growth. A photograph of a deformed tungsten coil heater is shown in Figure 28. The asterisk in the right hand column of Table VI indicates replacement of the coil heater. The heat source was changed to the lithium-TZM heat pipe, designated the RCA-J-15330, after 243 hours of elapsed life.

Examination of the sweep displays indicate that no change occurred in the device between 0 and 100 hours; the failure point of the first coil heater. With the installation of the second coil heater, a gradual improvement in E vs I characteristic was noted. Figures 22 and 23 illustrate this change. However, following installation of the third coiled heater at 181 hours, the converter characteristics again declined and again exhibited a slow improvement. Maximum performance occurred at 221 hours of elapsed time as shown in Figure 25. (Where $E = .45$ volts; $I = 480$ amperes, resulting in a power density of 4.32 watts/cm^2 and when $E = .50$ volts, $I = 425$ amperes, a power density of 4.25 watts/cm^2 with the emitter temperature at 1763°K)° The coil heater again failed. At this point, the heat pipe was fitted to the converter by press fitting the matched taper section on each part. A photograph of this assembly, mounted on the plate of the vacuum bell jar, is shown in Figure 29. The heat pipe was wrapped with (12) layers of serrated molybdenum foil to reduce radiation losses. The heat pipe was heated by passing AC current directly through the wall of the pipe evaporator section. Since the current carrying power leads were water cooled, a large thermal power drain was incurred thus necessitating a large gross power input to the heat pipe. The initial operational data displayed on the oscilloscope is shown in Figure 26.

FIGURE 28 PHOTOGRAPH OF DEFORMED TUNGSTEN
COIL HEATER

FIGURE 29 PHOTOGRAPH OF HEAT PIPE ASSEMBLED TO
CONVERTER IN OPERATING CONDITION

The flow of cooling water to the collector water cooling jacket was interrupted between 243 and 263 hours of operation. This interruption of water flow allowed the collector to rise to 1123° K for a period of four hours before detection. A light metallic deposit was noted on the bell jar in the vicinity of the converter. It is believed that cesium diffused through the braze joints attaching the ceramic insulator during this high temperature period. Twelve molybdenum thermal conduction pins were removed to reduce thermal conduction from the water cooling jacket. This change permitted an increased flow of cooling water through the jacket. Life test was again resumed, however, the AC sweep characteristic of the converter displayed a marked reduction in converter electrical performance.

A minor failure occurred in the top electron beam weld on the heat pipe at 351 hours of total elapsed life. The weld area was repaired by electron beam welding and the converter and heat pipe reinstalled in the vacuum bell jar. The AC sweep display indicated no further change in performance after the accidental loss of cooling water to the collector water jacket. The heat pipe weld again failed at 378 hours of elapsed life and forced termination of the test. The weld failures occurring in the heat pipe were attributed to the erratic performance of the electron beam welder during this period of fabrication. The failures were not considered fundamental to this fluid and material because of previously demonstrated long life.

SECTION III

CONCLUSIONS

The process to remove traces of residual halide contamination in cesium by combination with barium metal at elevated temperatures and at high vacuum proved successful. The resulting tertiary compound of Ba Cs CL did not co-distill from the reaction vessel along with the cesium being loaded in processing vials. Spectrographic analysis of a sample vial established the absence of halides.

The successful manufacture of a large surface area to volume ratio of molybdenum matrix was also achieved. By using a fine powder (-325) mesh and varying compacting pressure, sintering temperature, sintering time and sintering atmosphere, a surface to volume storage area of $5.27 \times 10^4 \text{ cm}^2/\text{cm}^3$ was obtained. The fabrication of this matrix employed no foreign materials which required removal during subsequent processing. The procedure encompassed dry pressing, high temperature-high vacuum firing and use of pure molybdenum powder. The processing procedures used to clean and assemble the thermionic converter parts were also successful in eliminating the formation of any deleterious products.

The fabrication of a cylindrical thermionic converter which contained an integral, large volume, internal molybdenum matrix reservoir was accomplished. The construction, processing, operation and life test of the RCA-A1345 converter demonstrated the validity of the proceeding work producing an operable internal reservoir converter.

The repeated malfunction of the thermal heat source for the converter posed a series of problems during life test evaluation. The E-I characteristics of the converter however did indicate a change in performance with the insertion of each new heat source. This change indicated a redistribution of cesium due to changing thermal patterns in the device. The observation of long term changes in electrical output to increased values after operation with a new heat source

confirms the slowly changing nature of cesium equilibrium however, the ability of the converter to operate successfully and stabilize at a high level of performance after each thermal cycle validates the fundamental design approach.

The loss of cooling water to the collector water jacket during life test did degrade the converter performance. It is believed that a large quantity of cesium was lost through the copper material contained in the insulator braze. The thermionic converter was still operable and produced electrical power after 378 hours of elapsed life despite the adverse thermal heat source and cooling water interruption problems.

APPENDIX A

CALCULATION OF CESIUM STORAGE

Measurements were obtained from BET surface adsorption tests made by Skinner & Sherman, Inc., New England Laboratories, Inc., Newton, Massachusetts on a test sample made of molybdenum matrix which is shown and described in Figure 13 of the First Topical Report, No. NYO3979-2. The sample was measured with argon gas and yielded a total surface of $S_T = .89M^2/\text{gram}$.

The total weight of the sample was 16.7611 grams thus, total surface volume of the sample = $.89 \times 16.7611 = 14.817M^2$. Since the volume of the sample was 2.8294 cm^3 , the surface storage area per unit volume of matrix is $5.272 \times 10^4 \text{ cm}^2/\text{cm}^3$.

The volume of the molybdenum matrix cast into the RCA A-1345 converter is:

O. D.	=	2.250 inches
I. D.	=	1.430 inches
Length	=	2.125 inches
Volume	=	4.8922 in^3
Volume	=	80.13 cm^3

The number of atoms of cesium in a monolayer is $4.8 \times 10^{14}/\text{cm}^2$ at (0) unity coverage on moly at 825°K and 5 torr. Thus, the number of cesium atoms stored is $4.8 \times 10^{14} \times 5.272 \times 10^4 \times 80.136 = 20.27 \times 10^{20}$ atoms. Since the number of cesium atoms per gram is $6.03 \times 10^{23}/132.91 = 45.36 \times 10^{20}$ atoms, the quantity of stored cesium is:

$$\frac{20.27 \times 10^{20}}{45.36 \times 10^{20}} = .446 \text{ grams}$$

APPENDIX B

ADSORPTION RESERVOIR CONVERTER CLEANING PROCEDURES

A. Chemical Cleaning and Vacuum Firing Schedule for All Parts and Subassemblies

(W-614C Wash Schedule)

1. Ultrasonic wash in trichlorethylene for 1 to 2 minutes.
2. Ultrasonic wash in demineralized water for 3 minutes.
3. Dip in methanol for 5 to 10 seconds.
4. Oven dry between 80° and 120° C.

B. Processing Procedures for All Parts and Subassemblies

1. Collector

- a. Rough machine blank.
- b. Vacuum fire between 900° and 950° C for 30 minutes.
- c. Finish machining.
- d. W-614C wash.
- e. Vacuum fire between 900° and 950° C for 30 minutes.

2. Outer Sleeve

- a. Rough machining blank.
- b. Vacuum fire between 900° and 950° C for 30 minutes.
- c. Finish machining.
- d. W-614C wash.
- e. Vacuum fire between 900° and 950° C for 30 minutes.

3. Pressed Reservoir Assembly

- a. Press moly powder as shown using tool No. 288-9-T1 (15 tons per square inch).
- b. Vacuum fire at 1800° C for 30 minutes.
- c. Finish machining.
- d. W-614C wash
- e. Vacuum fire at 900°C for 2 hours.

4. Moly Window Pipe

- a. Machine as shown.
- b. W-614C wash.
- c. Vacuum fire between 900° and 950° C for 15 to 30 minutes.

5. Electron Beam Weld Window Pipe to Pressed Reservoir Assembly

6. Collector Lead

- a. Machine as shown.
- b. W-614C wash.
- c. Vacuum fire between 900°C for 15 to 30 minutes.

7. Collector Weld Ring

- a. Machine as shown.
- b. W-614C Wash.
- c. Vacuum fire between 900° and 950° C for 15 to 30 minutes.

8. Electron Beam Weld Collector Lead and Collector Weld Ring to Pressed Reservoir Assembly
9. Heat Shield Mount
 - a. Machine.
 - b. W-614C wash.
 - c. Vacuum fire between 900° and 950° C for 15 to 30 minutes.
10. Heat Shield Retainer
 - a. Machine.
 - b. W-614C wash.
 - c. Vacuum fire between 900° and 950° C for 15 to 30 minutes.
11. Wrapped Heat Shield
 - a. Make 40 wraps.
 - b. W-614C wash.
 - c. Vacuum fire between 900° and 950° C for 15 to 30 minutes
12. Heat Shield Assembly
 - a. Assemble shield package. Electron beam weld flanges.
 - b. Vacuum fire between 900° and 950° C for 15 to 30 minutes
13. Electron Beam Weld Shield Packages to Collector Assembly
14. Strain Ring
 - a. Machine as shown.
 - b. W-614C wash.
 - c. Vacuum fire between 900° and 950° C for 15 to 30 minutes.

15. Insulator
 - a. Metalize.
16. Solder Washer
 - a. W-614C wash.
17. Insulator Assembly
 - a. Braze (copper-1100° C).
18. Expansion Ring
 - a. Machine.
 - b. W-614C wash.
 - c. Vacuum fire between 900° and 950° C for 15 to 30 minutes.
19. Expansion Assembly
 - a. Electron beam weld.
20. Closure
 - a. Machine.
 - b. W-614C wash.
 - c. Vacuum fire between 900° and 950° C for 15 to 30 minutes.
21. Expansion Assembly to Insulator Assembly
 - a. Electron beam weld assembly.
 - b. Leak check and cycle (25-900-25° C) in vacuum.
 - c. Leak check.
 - d. W-614C wash.

22. Emitter Lead
 - a. Machine.
 - b. W-614C wash.
 - c. Vacuum fire between 900° and 950° C for 15 to 30 minutes.
23. Emitter Contact to Insulator Assembly
 - a. Leak check.
 - b. Vacuum fire between 900° and 950° C for 15 to 30 minutes.
 - c. Leak check.
 - d. W-614C wash.
24. Complete Collector Assembly to Adsorption Reservoir Assembly.
 - a. Electron beam weld.
 - b. Leak check.
 - c. W-614C wash.
25. Emitter
 - a. Rough machine blank.
 - b. Vacuum fire between 900° and 950° C for 15 to 30 minutes.
 - c. Finish machine.
 - d. W-614C wash.
 - e. Vacuum fire between 900° and 950° C for 15 to 30 minutes.
26. Complete converter assembly
 - a. Electron beam weld.
 - b. Leak check assembly through a cold trap.

27. Window Adaptor

- a. Machine.
- b. W-614C wash.

28. Still Adaptor

- a. W-614C wash.

29. Sapphire Window

- a. Machine.
- b. W-614C wash.

30. Window Assembly

- a. Heli-arc Weld in Argon
- b. Leak check.
- c. W-614C wash.

31. R. F. Braze Window Assembly to Converter with Nickel-Palladium Alloy
in Hydrogen Atmosphere

NOTE: Vacuum Firings Accomplished at Pressures Less Than 10^{-5} Torr.

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