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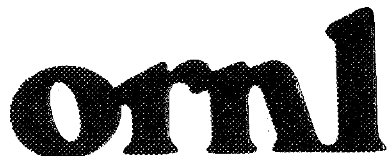

OAK RIDGE
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MARTIN MARIETTA

Plating Nickel-63 on Copper Coupons

M. Petek
J. S. Wike
B. P. Phillips
C. A. Sampson

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MARTIN MARIETTA ENERGY SYSTEMS, INC.
FOR THE UNITED STATES
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Chemical Technology Division

PLATING NICKEL-63 ON COPPER COUPONS

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PLATING NICKEL-63 ON COPPER COUPONS

M. Petek, J. S. Wike, B. P. Phillips, and C. A. Sampson

ABSTRACT

A method suitable for hot-cell operations was developed to electroplate ^{63}Ni-enriched nickel on copper. Efficient utilization of the limited quantity of available radioisotope material was a primary concern. The isotope was prepared by neutron irradiation of nickel metal enriched in ^{62}Ni by the reaction

$$^{62}\text{Ni} + n = {}^{63}\text{Ni} + \gamma.$$

The irradiated nickel was dissolved in HCl, and the solution was passed through an ion exchanger to eliminate traces of radioactive isotopes cogenerated from the impurities present in the sample. The purified nickel chloride was converted to sulfate, and a stock solution was prepared. The electroplating solution consisted of ammonium sulfate, ammonia, and a small amount of a surfactant, to which an aliquot of the ^{63}Ni stock solution was added. The unused portion of nickel sulfate would be regenerated from this solution by merely heating to remove all the other components. Uniform, well adherent deposits were obtained. From the original 4.67 g of nickel enriched in ^{63}Ni, 2.6 g was plated on copper, 1.52 g remained as unused nickel sulfate, and 0.55 g was lost in the process.

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1. INTRODUCTION

A constant electron flux was needed for developmental work in beta-cell technology. A relatively long-lived beta emitter that could be applied in a layer of defined thickness to an appropriate substrate was required. The radioisotope ^{63}Ni was selected because of its beta-emitting properties, its half-life of about 100 years, and its ability to be electroplated to a desired thickness under controlled conditions

without considerable losses of the isotope material. For very thin layers, the beta/gamma radioactivity is proportional to the thickness of the ^{63}Ni layer; however, after a certain thickness is reached, it remains practically constant due to the self-shielding effect. The optimum thickness of the ^{63}Ni layer (i.e., a constant electron flux with a minimum amount of the isotope) can be determined by a set of samples of various thicknesses of the electroplated nickel. The isotope can be prepared by neutron bombardment of nickel metal previously enriched in ^{62}Ni by calutron separation. Because of the high radiotoxicity of ^{63}Ni, a hot cell is required for work with this isotope.

2. EXPERIMENTAL

Mirror-finish, machined copper coupons were used as the substrate. The coupons for evaluation of the optimum thickness of the electroplated nickel we
3.3 x 2.54 x 0.16 cm thick, with a 2.6 x 2.1 cm (5.46-cm^2) area to be plated.
coupons for the beta-cell technology developmental work were
5.08 x 5.08 x 0.025 cm thick, with a 4.45 x 4.29 cm (19.1-cm^2) area to
The coupons, as supplied, were protected with a plastic paint that w
prior to plating.

The following thicknesses of electroplated nickel were req

	Thickness (µm)	Areal density (mg/cm^2)	Weig (r
SMALL PLATES: (2 each)	0.25	0.22	
	0.50	0.44	
	0.75	0.66	
	1.0	0.88	
	2.0	1.76	
	3.0	2.64	
LARGE PLATES (as many as possible from the available ^{63}Ni solution)	2.0	1.76	

2.1 PRELIMINARY EXPERIMENTS WITH NORMAL NICKEL

The characteristics of the plating solution were chosen such that nickel could be plated efficiently from relatively dilute solutions to form a uniformly thick, adherent deposit. At the same time, it was necessary to recover the isotope from the partially exhausted plating solution and to reuse it for further plating in a manner which was practical for hot-cell working conditions. A plating solution recommended for exhaustive plating consists of nickel sulfate dissolved in a solution containing $(NH_4)_2SO_4$ at a concentration of 12.0 g/L in 0.15 N NH_4OH.[1] From this plating solution, the original nickel sulfate could be conveniently recovered by simply evaporating the solution to dryness and decomposing the excess of ammonium sulfate by heating the dry residue to 300-400°C in air.

2.2 PLATING CELL

Two plating cells were designed, one for plating the small coupons (Fig. 1) and another for plating the large ones. The same principle was used in each case, except that the dimensions were modified to accommodate the different coupon size. The base of the plating cell was machined from a thick copper plate which served as the support for positioning the copper coupons. Two threaded steel rods were fastened to the base and served as the guide for the rectangular plexiglass cell body to slide over the coupons. A Viton gasket was placed between the plexiglass walls and the coupons to prevent leakage of the plating solution. Two wing nuts were used to press the cell body tightly over the coupons. A plexiglass cover was used to hold the platinum anode in place. The anode was made of a rectangular piece of platinum foil, almost the same size as the coupons, to ensure a uniform electric field between the two electrodes, which was a necessary condition for obtaining a uniform electroplate. A few holes were punched in the platinum anode to provide an escape route for gases that m formed during the process. A platinum rod was welded to the center of the a

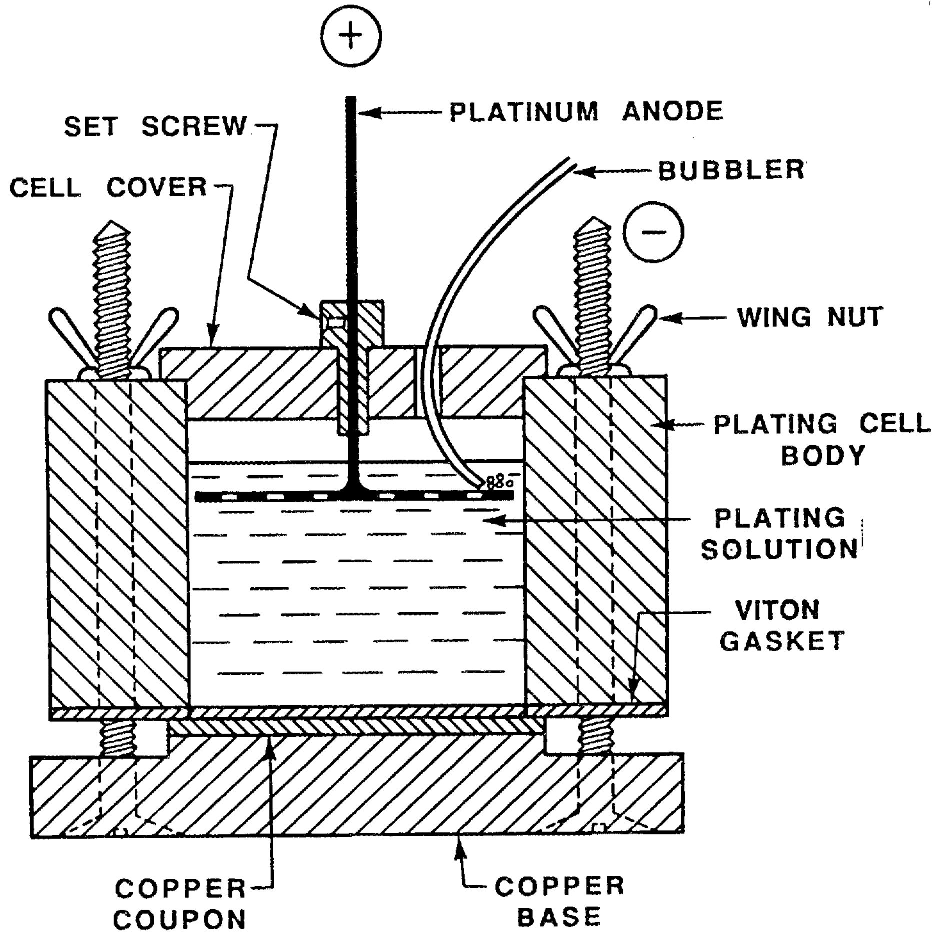

Fig. 1. Electroplating cell assembly.

providing electrical contact and a means for adjusting the relative position of the electrodes. The cell cover was also provided with a bubbler that was used to stir the solution during the plating process.

2.3 INSTRUMENTATION

The power source was a potentionstat/galvanostat (Model 371; Princeton Applied Research Corporation) used in the galvanostatic mode. The cell voltage was monitored during the plating process with a Linseiss strip-chart recorder (Model LD 12). Typical voltage response during the plating process is shown in Fig. 2(a). Deviations from the normal voltage/time scans were indicative of problems in the plating process, and appropriate corrective actions were applied. Such a problem occurred for the sample shown in Fig. 2(b), where an accidental decrease in pH to 1.5 (instead of the desired level of 9) caused the cell voltage to drop considerably.

The temperature of the process was controlled by using a thermocouple probe, inserted in a hole drilled in the hot plate, and an electronic temperature controller.

2.4 PLATING CONDITIONS

The optimal plating conditions were determined in a study carried out with normal nickel sulfate. The ammonium sulfate and ammonia concentrations of the plating solution were kept constant. The effects of surfactant concentration, stirring, temperature, current density, and nickel concentration on the quality of the nickel plate were evaluated. The results obtained for each of these plating parameters are discussed below.

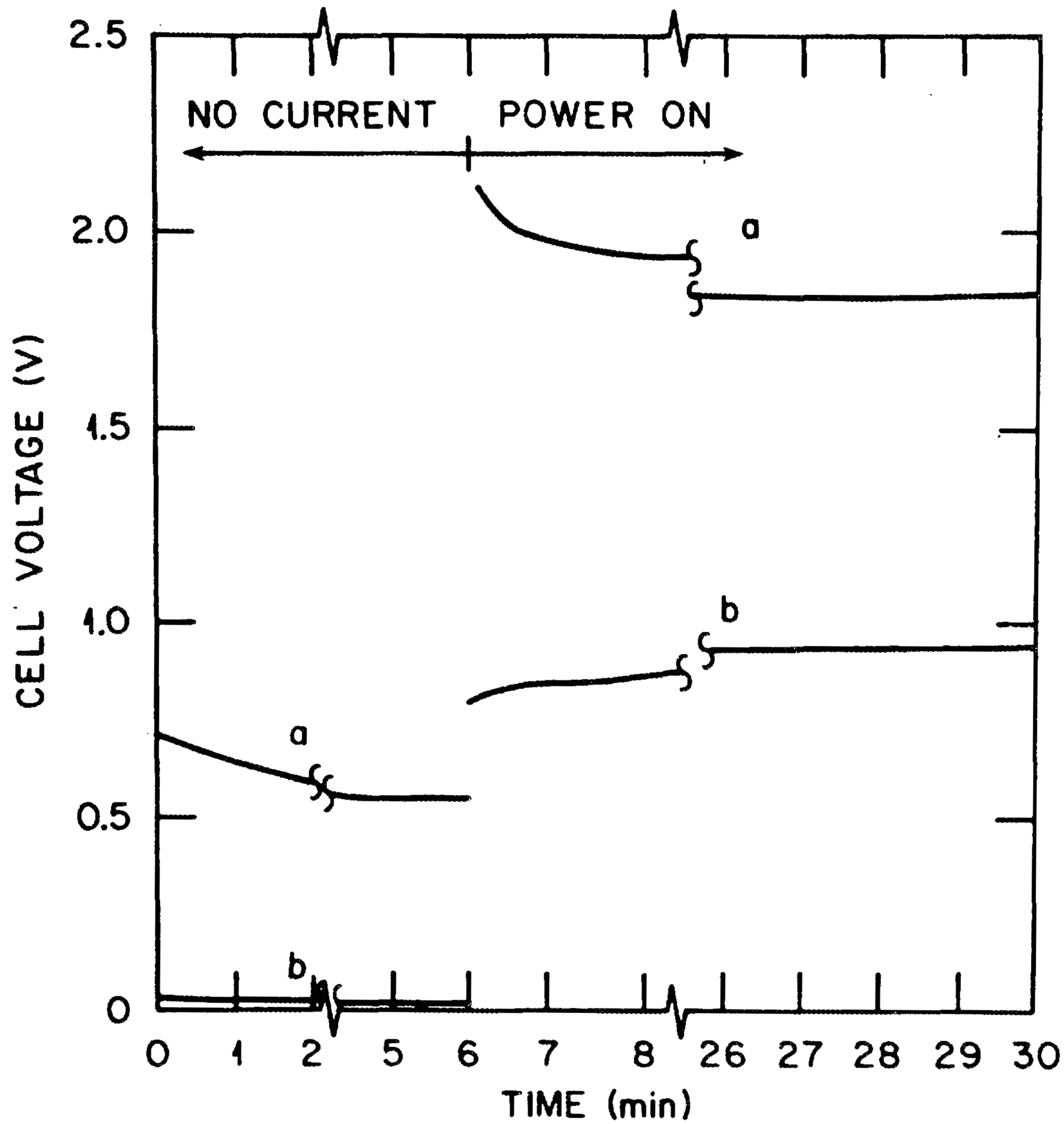

Fig. 2. Typical voltage-time curves before and during the plating process. (a) Normal plating solution (pH = 9); (b) plating solution contaminated with acid (pH = 1.5).

2.4.1 Surfacant Concentration

During the initial plating attempts, two adverse phenomena were observed. First, the electroplated nickel had a dull, velvety appearance and could be partially wiped off; and second, a few bubbles were generated at the copper cathode (most likely consisting of cogenerated hydrogen). These bubbles stuck to the cathode during the entire process, leaving small dots of nickel-free copper. The addition of small amounts of surfactant (4×10^{-4}% TWEEN-80*) improved the adherence of the nickel plate, but its appearance was still dull. The bubbles at the cathode could be removed by shaking the cell or by applying an upward stream of the plating solution. Therefore, a pumping system was devised to stir the plating solution.

2.4.2 Stirring

A simple apparatus for stirring was constructed using a 100-mL polyethylene bottle that was provided with a disposable plastic pipet. A 4-mm-OD x 1-mm-ID length of surgical tubing was attached to the pipette tip, and a short, 2-mm-diam, thin-walled Teflon tube was inserted in the other end. The Teflon tube was then immersed in the plating solution. The polyethylene bottle was placed upside down, against a firm plate, and a plunger connected to a slow motor squeezed it periodically (five strokes per minute) against the plate. A small portion of the plating solution was pumped in and out of the Teflon tubing, thereby stirring the plating solution and providing a periodical upstream motion of the liquid which carried away the few bubbles occasionally formed at the cathode. The position of the tubing within the plating cell was found to be of utmost importance for obtaining a uniform deposit. Data obtained in a number of experiments showed that the best position is just above the platinum anode so that a direct "jet stream" was dispersed at the anode before reaching the cathode (see Fig. 1). Positioning

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*Trademark of ICI Americas, Inc.

the end of the tubing below the anode resulted in a nonuniform distribution of the nickel plate. Uniform and shiny layers of nickel were obtained using this system.

2.4.3 Temperature

The plating assembly was placed on a hot plate with a glass plate inserted between the hot surface and the copper bottom of the cell to provide electrical insulation. The temperature was controlled at 50°C since the early tests showed that the nickel deposit was dull at room temperature and excessive bubble formation occurred at higher temperatures (70-90°C). When the plating cell was moved to the hot cell, it was necessary to increase the hot-plate temperature setting to 55-62°C in order to obtain the same quality of the plate. A small temperature probe within the plating solution would have furnished a better control, but this was not practical for the hot-cell work. This higher temperature setting was probably needed because of the faster heat loss from the plating solution in the hot cell compared with that in the laboratory.

2.4.4 Current Density

Good-quality deposits were obtained at a current density of 2.75 mA/cm^2. When the current density was doubled, dull, poorly adherent deposits were obtained. Lower current densities would have prolonged the plating time unnecessarily. Therefore, a current density of 2.75 mA/cm^2 was used for all plating conditions.

2.4.5 Nickel Concentration

Several platings were performed at the following conditions:

Plating solution: 12 g/L $(NH_4)_2SO_4$ in 0.15 N NH_4OH
1.25 mg Ni/mL added in the form of a $NiSO_4$ solution
4 x 10^{-4}% surfactant (TWEEN-80)
pH ~2.9
Temperature: 50°C
Current density: 2.75 mA/cm^2
Plating time: 20 min

At these conditions, the average plating rate was 0.04 mg Ni per cm^2 per minute. Using the above conditions, six electroplatings were performed at different plating times in order to obtain the required six different nickel thicknesses (see Table 1).

Table 1. Electroplating results

Sample No.	Thickness (μm)	Plating time (min)	Percent yield
26	0.25	5.5	98
27	0.50	11.0	89
28	0.75	16.5	96
29	1.00	22.0	94
30	2.00	44.0	77
31	3.00	66.0	71

It is evident from Table 1 that the plating rate decreases as the plating time increases. The most likely reason for this behavior was the decrease in nickel concentration during the plating process. Therefore, the concentration of nickel

was increased from 1.25 mg/ml to 1.75 mg/mL. The resulting plating time/yield relationship remained practically the same (Fig. 3), but the appearance of the nickel plate was improved with the more concentrated nickel; therefore, 1.75 mg Ni/mL was adopted for further platings. In order to obtain the desired thickness, the plating time was estimated using data from Fig. 3. The curve showing the obtained thickness as a function of plating time approached asymptotically the theoretical straight line for 100% current efficiency. At higher nickel concentrations, the experimental points are closer to the theoretical values.

All these preliminary experiments were performed in the small cell. There was practically no change in any of the plating conditions when switching from the small cell to the large cell, except for the increase in the volume of the plating solution and also in the current for maintaining the same current density.

2.5 PLATING PROCEDURE

At the conclusion of the developmental experiments, a plating procedure was adopted, and it was strictly followed except when unforeseen circumstances required minor modifications. Such cases were experienced when working in the hot cell, and they will be discussed later.

The schematic of the experimental setup is shown in Fig. 4. First, the hot plate was turned on to reach the working temperature. Then the copper coupon to be electroplated was stripped of its protective plastic layer by peeling it off carefully, so that the mirror polished surface would not get scratched or be otherwise damaged. The peeling process was started at one of the corners, using a fine-edged tool; and after enough material had been lifted off the copper, the procedure was continued with tweezers. In most cases, the bare copper surface was spotted with some residue that was removed by soaking the coupons in toluene, followed by thorough toluene and methanol rinses. The clean, dry coupons were weighed with an analytical balance to five decimal places, placed on the cell base, and aligned. The plexiglass cell body was slipped over the posts and fastened with the wing nuts. The assembled cell was placed on the hot plate,

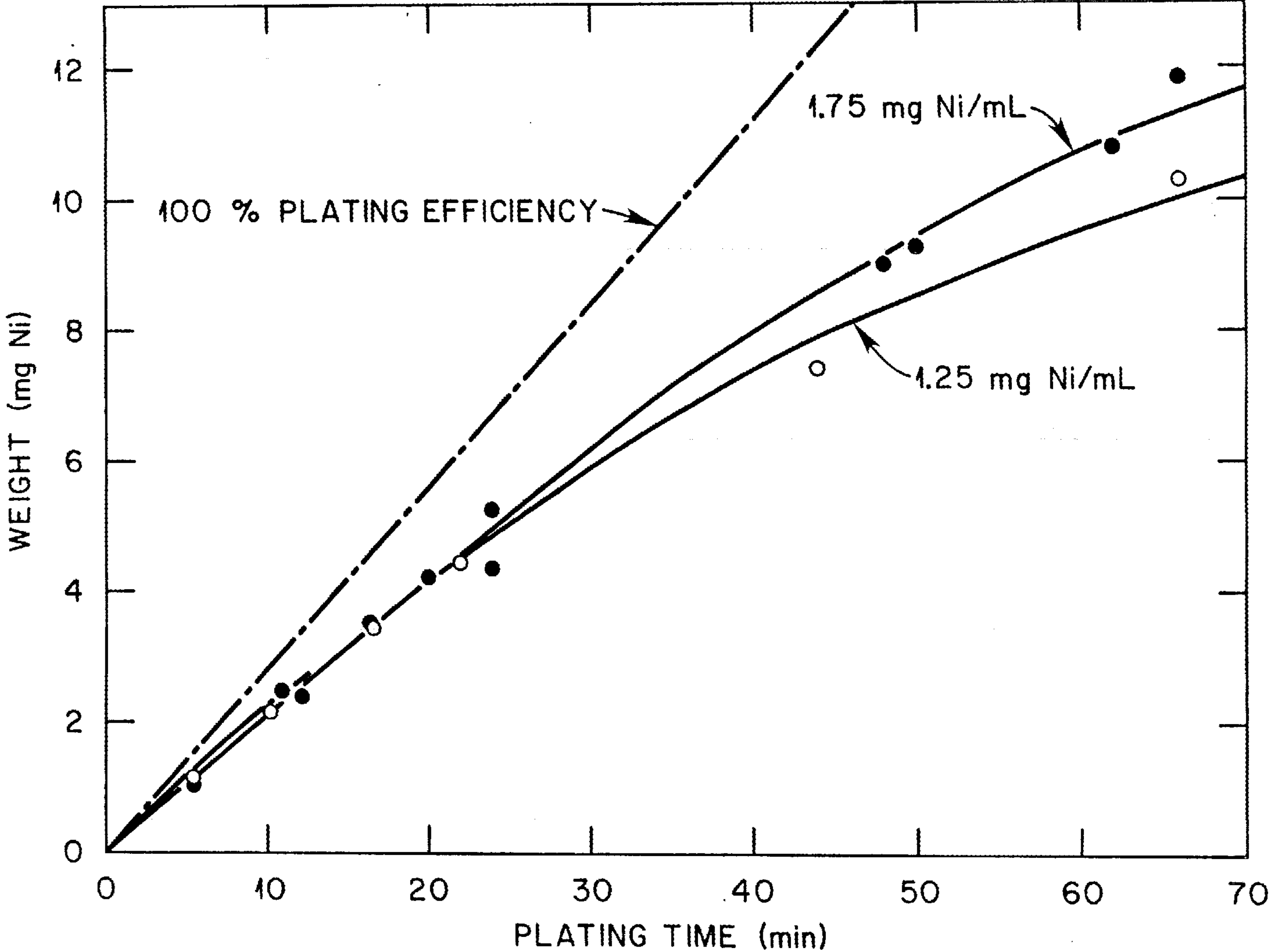

Fig. 3. Weight of the electroplated nickel as a function of plating time.

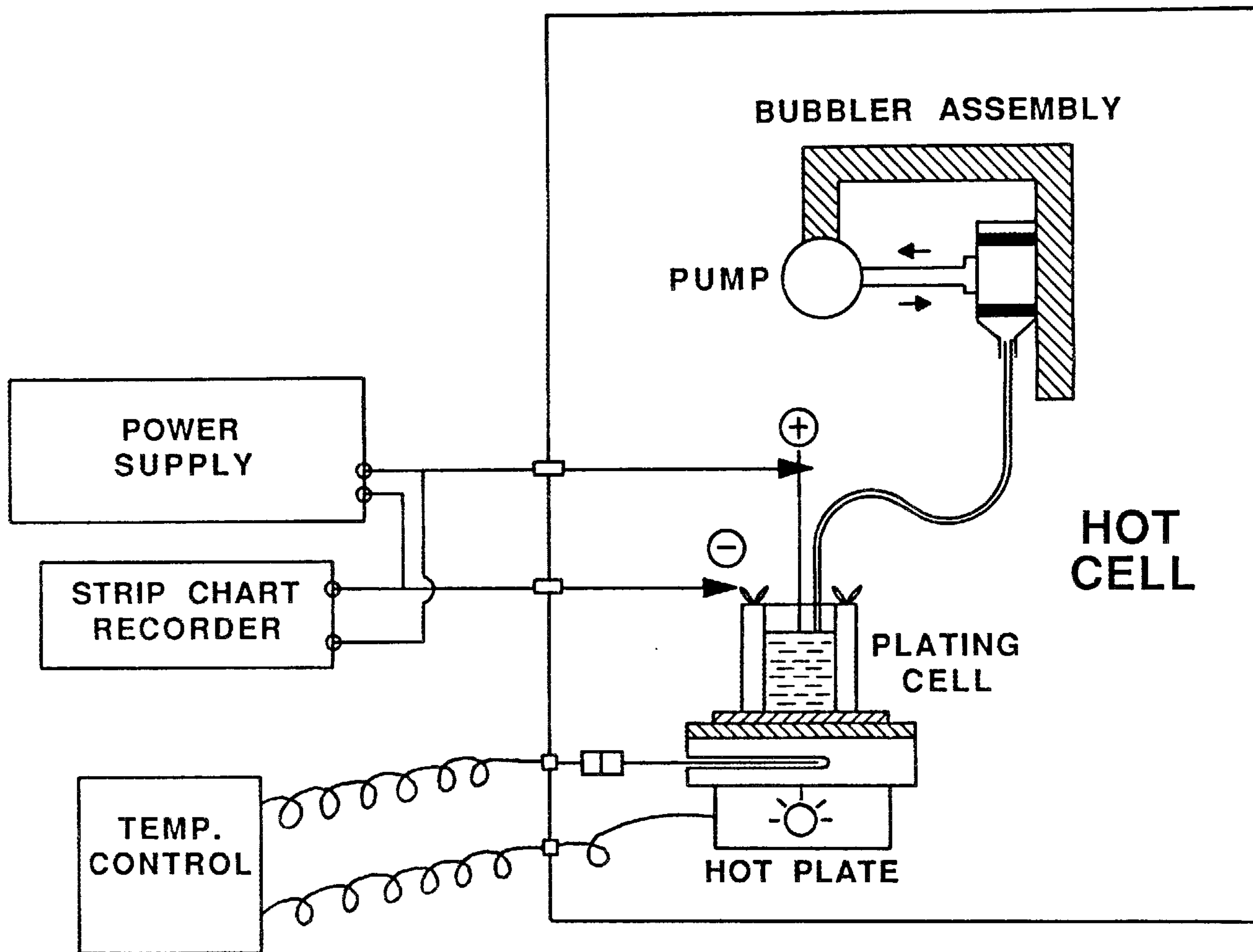

Fig. 4. Electroplating setup in the hot cell.

which was provided with an electrically insulated layer. The required volume of the plating solution (20 mL for the small cell and 65 mL for the large cell) was placed in the cell, and an aliquot (<1 mL) of the concentrated nickel sulfate stock solution was added.

Prior to placing the cover on the cell, the platinum anode, the bottom side of the cover, and the end of the Teflon tubing were thoroughly rinsed with distilled water. The clean top was placed on the cell, the motor of the mixer pump turned on, and the mixing action started. The electrodes were connected to the power supply, and the recorder was turned on. The voltage drop between the electrodes with no current flowing through the cell was determined to be 0.4 to 0.6 V, copper being negative (see Fig. 2). Usually, it took a few minutes for the cell voltage to attain a constant value, and this was a good indicator that the plating solution had warmed up to the working temperature. The required voltage was preset on the power supply to produce a constant current through the cell (15 mA for the small cell and 54.9 mA for the large cell; galvanostatic mode), and the cell current was turned on. The plating was carried out for a predetermined period of time, after which the cell current was turned off, the leads to the electrodes disconnected, the pumping stopped, and the cover taken off the cell.

The platinum anode was usually covered with a black-brown layer, especially after long plating times. The electrode was cleaned by placing the cell cover over a glass beaker filled with approximately 6 N HNO_3 so that the anode was immersed into the acid at approximately the same level as it was immersed into the plating solution. The black-brown layer dissolved almost immediately. The cell solution was poured out of the cell, and the cell was rinsed several times with distilled water before it was disassembled. The coupon was taken out, rinsed again with distilled water followed by a thorough methanol rinse, and dried in air. Dry coupons were weighed and the amount of plated nickel determined from the weight difference before and after plating. The sequence was repeated for each subsequent plating. It was very important to wash out all the residual nitric acid from the plating cell cover; otherwise, the pH of the plating solution would drop and the nickel would

not plate out. The effect of pH of the plating solution is discussed further in Sect. 2.8.1. The results of plating the small coupons are given in Table 2.

Table 2. Small coupons with variable electroplate thickness

Coupon No.	Thickness (μm) Nominal	Thickness (μm) From weight	Weight (mg) Expected	Weight (mg) Actual	Plating time (min)
024	0.25	0.29	1.22	1.4	5.5
034	0.25	0.20	1.22	1.0	5.0
037	0.50	0.53	2.43	2.6	12.5
038	0.50	0.53	2.43	2.6	16.0
025	0.75	0.76	3.66	3.7	24.0
035	0.75	0.80	3.66	3.9	12.5+5[a]
039	1.00	1.03	4.86	5.0	25
028	1.00	0.91	4.86	4.4	20
030	2.00	1.87	9.72	9.1	40+17
042	2.00	2.10	9.72	10.2	54
031	3.00	3.12	14.50	15.1	70+15[a]
032	3.00	3.04	14.50	14.7	60+13[a]

[a]Wherever two numbers for the plating time are given, it means that the desired thickness was not achieved in the first plating (first number); therefore, a second plating (second number) was performed to obtain the proper value.

2.6 EVALUATION OF THE ELECTROPLATED LAYER

During the development studies, four of the small coupons electroplated with normal nickel were cut lengthwise, mounted in epoxy, and polished; then the cross sections were examined by a scanning electron microscope (SEM). At 1000X magnification, the nickel layer appeared to be quite uniform, compact, and well adherent. Photographs were taken from the center portion and from the edges of

the plated area; no difference was found between these areas. The advantage of this method was the ability to directly observe the interface between the base metal and the electroplate. The disadvantage was that only a small area could be observed at one time. The thicknesses of the electroplated nickel for the four examined samples, as measured by the SEM, are shown in Fig. 5 as plots vs the thicknesses expected from the weight difference. As a complement to the electron microscopy, another set of coupons was scanned with a profilometer.* In this case, the entire coupon can be reasonably well mapped by running several scans across the samples at seven positions as shown in Fig. 6. Generally, scans at positions 1-4 were concave, and scans at positions 5-7 were convex. From these scans, the general appearance of the copper surface curvature prior to nickel plating was constructed (Fig. 6). Five coupons with different amounts of nickel electroplated were scanned. The average nickel thickness on each coupon was calculated from the seven profilometer scan printouts. These values are also shown (full circles) in Fig. 5. The nickel plate thicknesses determined both from the SEM photographs and from the profilometer scans are quite close to those calculated from the weight of the electroplated nickel. The data obtained from the SEM follow the theoretical straight line but are about 0.4 μm thicker than expected. This is probably caused by the way the thickness was measured and involves a systematic error. The profilometer scans have the advantage that they reflect the overall surface; however, due to the inherent curvature of the original coupons, the determination of the plate thickness becomes subject to gross errors as the thickness diminishes. Two typical profilometer scans of nickel-plated coupons are shown in Fig. 7. It is evident that for the thin deposit, the step from the copper base to the nickel deposit barely exceeds the roughness background; therefore, the error in determining the thickness is appreciable. In contrast, for the

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*DEKTAK IIA-6; marketed by the Sloan Technology Corporation.

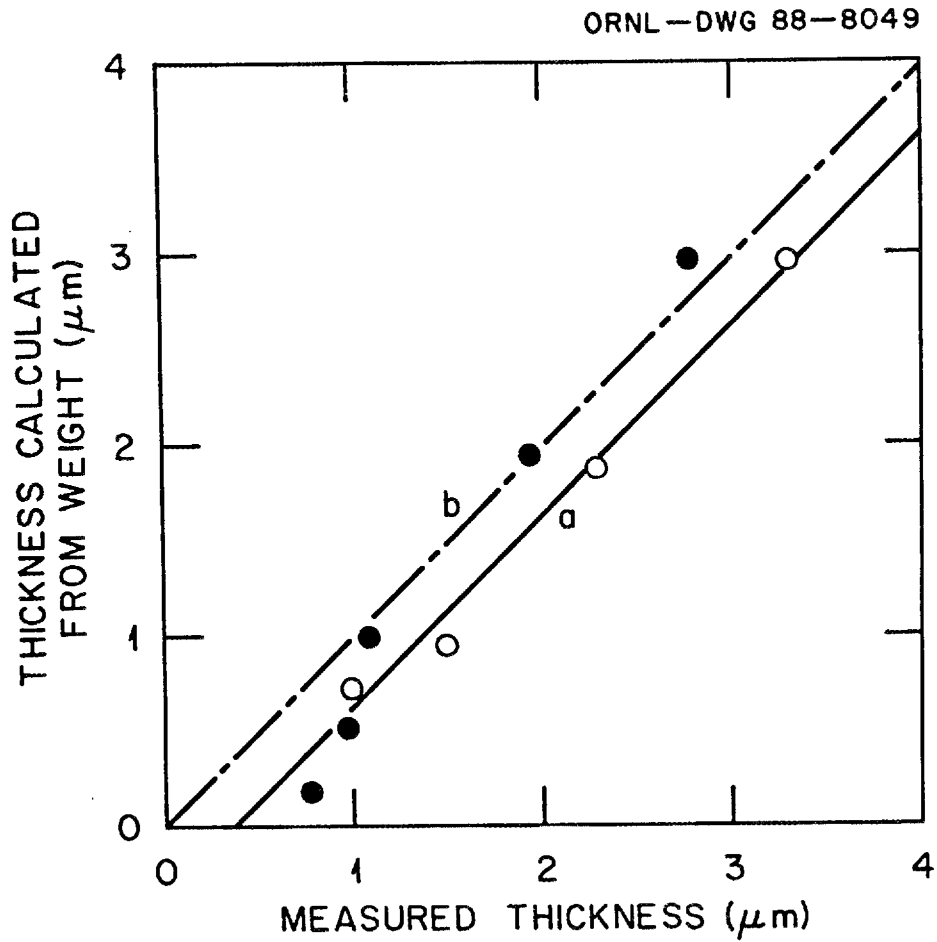

Fig. 5. Thickness of electroplated nickel determined by weight vs thickness measured from SEM photographs (○) and by profilometer scans (●).

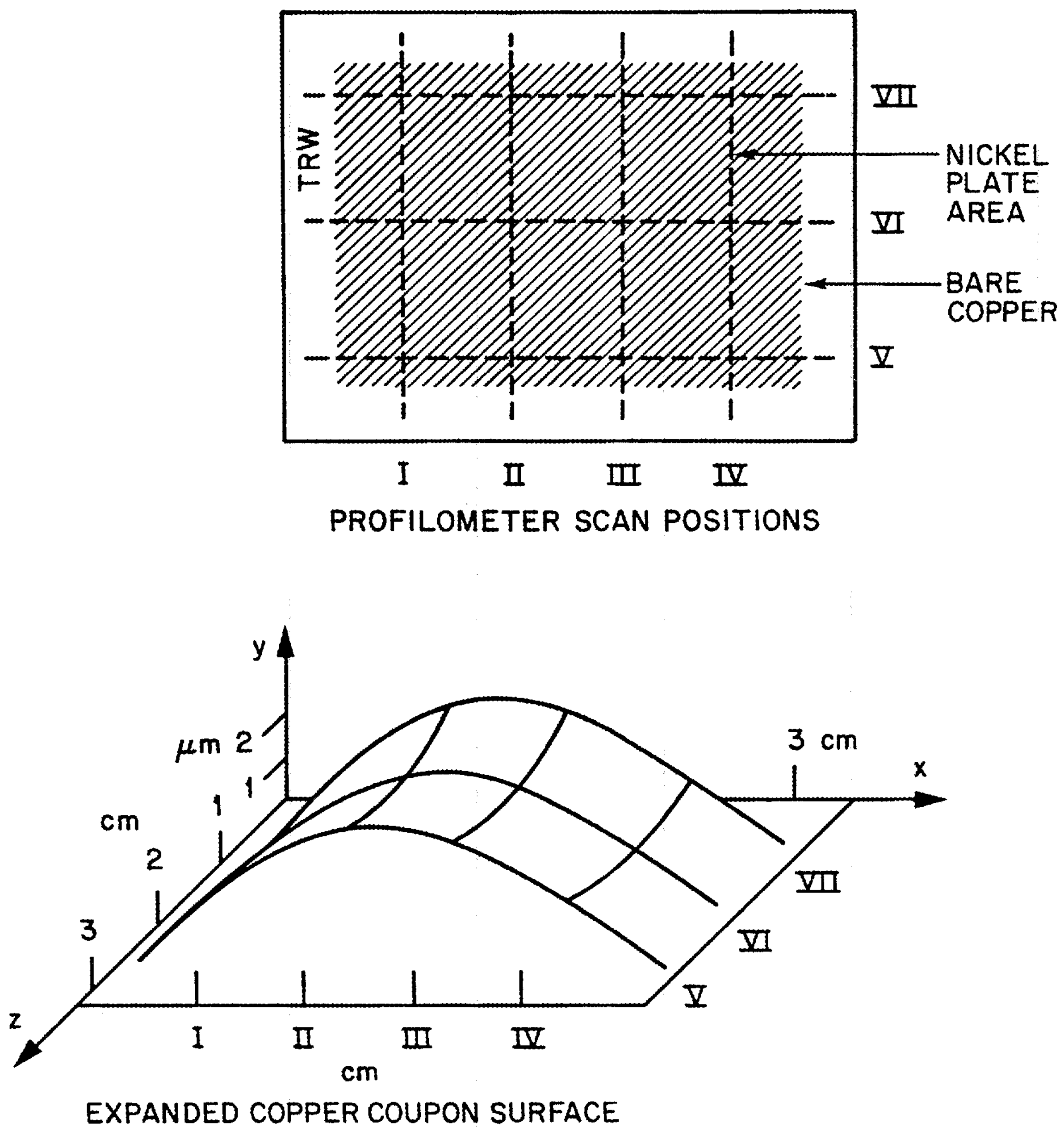

Fig. 6. Profilometer scans over bare copper coupons. The scans were taken lengthwise over 25 mm (scans I, II, III, IV), and across the coupon over 21 mm (scans V, VI, VII).

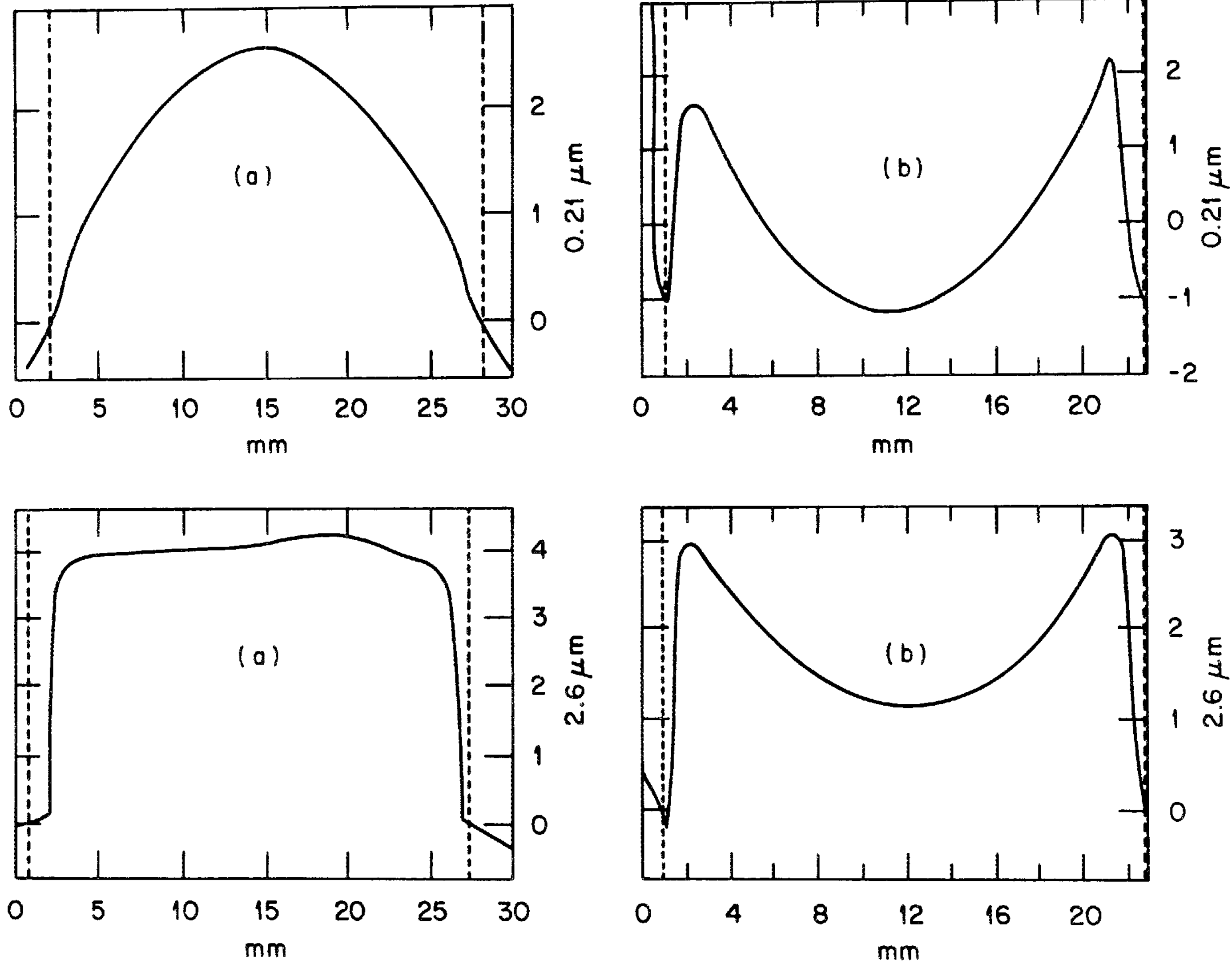

Fig. 7. Profilometer scans for 0.2l-μm (top) and 2.6-μm electroplated nickel (a) taken lengthwise and (b) across the coupons.

thick nickel deposit, the step from copper to nickel plate is clearly pronounced and can be measured quite accurately.

2.7 CHEMICAL TREATMENT OF ^{63}Ni-ENRICHED SOLUTIONS

Two targets enriched in ^{62}Ni were irradiated in the High Flux Isotope Reactor (HFIR) at Oak Ridge National Laboratory (ORNL) to produce ^{63}Ni. The first target consisted of 6.94 g of 27% enriched nickel (designated as 27A and 27B). The A and B designators referred to two quartz ampules that contained the 27% enriched nickel during its irradiation. This material was irradiated and was used for the development of procedures for plating ^{63}Ni. The second target, which was made up of 4.67 g of 46% enriched ^{62}Ni, was irradiated for the final plating solution.

Both enrichments were contained in the same irradiation target. At the end of the irradiation period, they were removed from the reactor to a remote operating cell that was equipped with master-slave manipulators and were opened. The quartz ampules were crushed, and the material was transferred into separate beakers for dissolution in nitric and hydrochloric acids. A gamma scan showed that some trace radionuclides had been produced along with the ^{63}Ni. The two most significant contaminants were ^{60}Co and ^{110}Ag. These were of such quantity that a decision was made to remove them chemically.

Moore and Kraus[2] demonstrated that cobalt is retained on anion-exchange resin in strong hydrochloric acid, while nickel is not. This technique was used to remove the cobalt to acceptable levels, although a two-step procedure was required. Moore and Kraus also showed that ^{110}Ag is retained on anion-exchange resin in very dilute hydrochloric acid.

A glass column was fitted with a glass wool plug to support the anion-exchange resin bed (Dowex A1X8, 50 to 100 mesh), which was 2 cm in diameter and 15 cm long. The resin was prepared for the ^{60}Co removal step by washing with three column volumes of 9 M HCl. The nickel targets were made up in ~50 mL of 9 M HCl and passed through the column at 40 drops (~2 mL) per

minute. The column was then washed with about 150 mL of 9 M HCl to remove traces of nickel that passed through the column. The retained cobalt was stripped from the column with 0.1 N HCl.

This procedure was repeated a second time to remove the ^{60}Co to lower-than-detectable limits in the products.

After the ^{60}Co removal was complete, the ^{63}Ni product solutions were evaporated to near dryness and taken up in distilled water. The resulting solution was approximately 0.1 N in HCl. A column equivalent to the one used for the cobalt removal was constructed with anion-exchange resin (Dowex A1X8; 50 to 100 mesh) and conditioned with several column volumes of 0.1 N HCl. The sample was percolated through the column. The ^{63}Ni passed through, but the ^{110}Ag was retained on the column. One pass through the column removed the ^{110}Ag to acceptable levels for plating solutions.

The purified ^{63}Ni solution in hydrochloric acid was evaporated to a small volume, and an excess of sulfuric acid was added to convert the nickel chloride to the sulfate. The solution was heated to near dryness, and distilled water was added to obtain a solution of ~70 mg of nickel per milliliter. When this solution was used for ^{63}Ni plating, it contained too much free acid, which lowered the pH of the plating solution to about 1.5. Therefore, the ^{63}Ni sulfate solution was again evaporated to dryness until no fumes were noticeable. Enough water was then added to make a solution containing 50 mg of nickel per milliliter.

2.8 ELECTROPLATING OF ENRICHED ^{63}Ni

The electroplating of the radioactive ^{63}Ni was performed in a hot cell following essentially the same procedure as for the normal nickel. The changes were as follows:

1. The temperature setting on the thermoregulator was increased from 50°C to 56-62°C. This change was needed because of the lower-ambient-temperature, high air flow in the hot cell compared with the laboratory where the developmental experiments were performed.

2. The plating cell was assembled in a hood approved for radioactive work. Rubber gloves were used when handling the electroplating cell and cell parts that had been in the hot cell and in contact with ^{63}Ni solution. The plating cell was assembled on a tray, filled with the proper amount of the plating solution (without ^{63}Ni), and transferred to the hot cell. The cell was placed on the hot plate, using mechanical manipulators, and the proper amount of the $^{63}NiSO_4$ solution was added with a pipette. The cell cover provided with the platinum anode and the bubbler tip was thoroughly washed with distilled water and placed over the cell. The plating was performed as described for normal nickel.
3. After each plating, the spent ^{63}Ni plating solution was poured into a beaker and saved for ^{63}Ni recovery. Also, the first rinse of the plating cell with distilled water was added to that beaker.
4. The thoroughly rinsed plating cell was placed in the transfer tray and taken to the hood. The electroplated coupon was removed from the plating cell and rinsed thoroughly with distilled water and methanol. After being allowed to dry, the coupon was weighed to determine the amount of the deposited nickel.
5. Steps 1 through 3 were performed to electroplate the next coupon. No particular care was taken to prevent contamination in the ^{63}Ni-free areas.

2.8.1 Problems

Maintaining the pH of the plating solution was found to be of paramount importance. On a few occasions, when the nitric acid from washing the anode/cell cover assembly was not completely rinsed off, the plating solution turned acid (pH $\sim$1.5 instead of $\sim$9). This resulted in excessive hydrogen evolution and no nickel plating. In preparing the ^{63}Ni plating solution, the original chloride needs to be completely converted to the sulfate, and the excess acid needs to be removed by heating the $NiSO_4$ under a heat lamp until no more fumes are generated.

Incomplete removal of excess acid will result in a low-pH plating solution and, consequently, in the absence of nickel deposits. A plating solution with a pH that is too low can be immediately detected by a cell voltage reading that is lower than usual (see Fig. 2) and by the color of the plating solution turning pale blue-green (nickel aquo complex) in acid medium, instead of blue-to-violet (nickel-ammonia complex), at a pH of ~9 in an ammoniacal medium.

2.8.2 Regeneration of $^{63}NiSO_4$

The exhausted plating solutions, as well as the first cell rinses with distilled water, were collected in a beaker. The solution was boiled down to a small volume under a heat lamp; then a few milliliters of sulfuric acid was added to ensure that all the nickel will end up in the form of sulfate. The final drying was achieved using a hot plate and the heat lamp. Some of the ammonium sulfate would persistently cling to the wall of the beaker. In order to sublime it completely, the beaker was cooled down, the wall washed with squirts of distilled water, and dried again. This step was repeated, if necessary. Finally, the $^{63}NiS0_4$ residue was dissolved in distilled water to make a solution containing nickel at a concentration of ~1.75 mg/mL.

The dependence of the radiation intensity on the thickness of the electroplated ^{63}Ni-enriched nickel is shown in Fig. 8. The radiation was measured with a cutie pie at "contact" [i.e., 38 mm (1.5 in.) away from the detector]. It is evident that the radiation intensity increases linearly with the increasing nickel thickness, up to about 0.6 μm. Above this value, the radiation remains practically constant due to the self-shielding of the nickel layer. Consequently, the thickness of 2 μm for the large coupons was shown to be sufficient for avoiding beta-emission fluctuations caused by minor nonuniformities of the electroplated layer.

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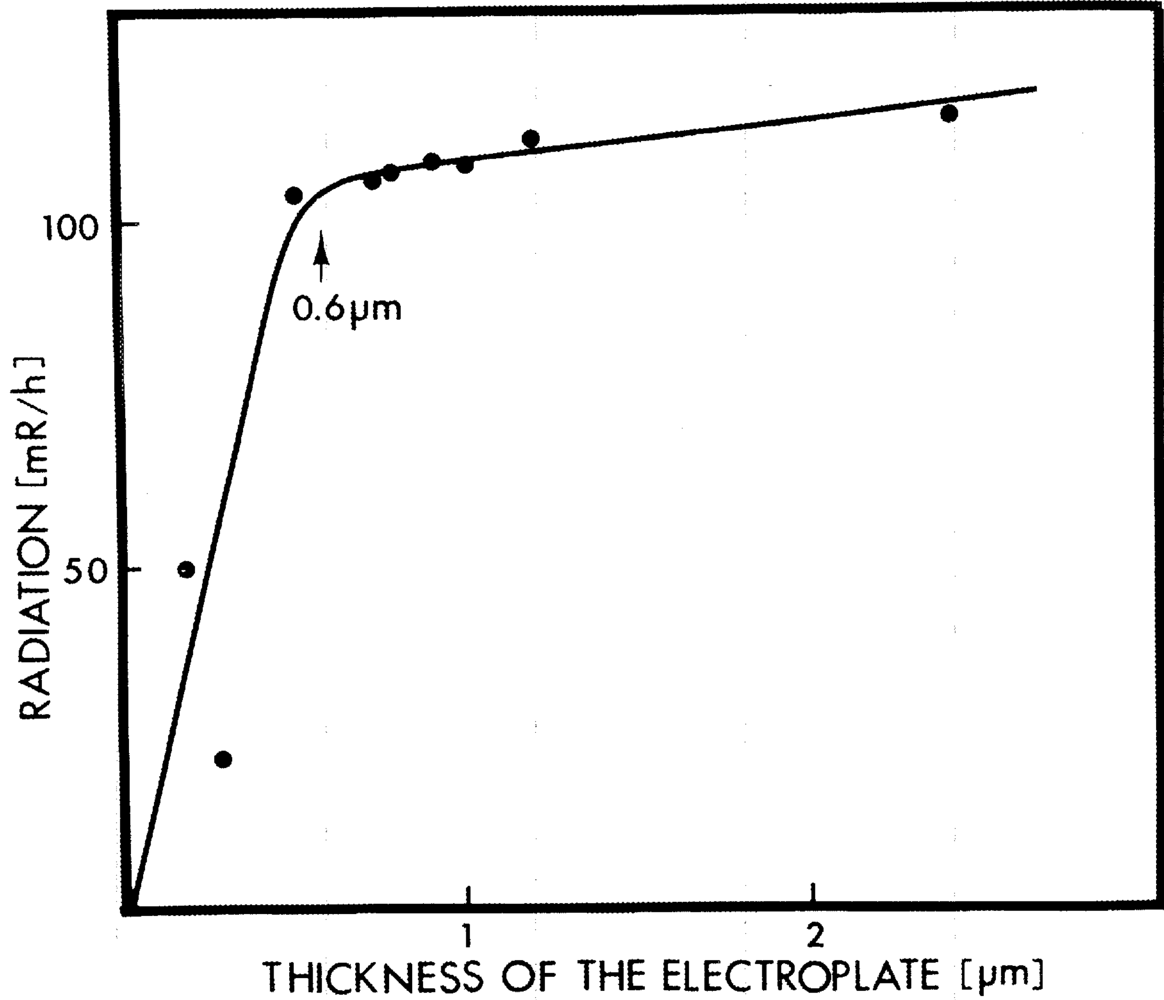

Fig. 8. Intensity of the radiation field 3.8 cm (1.5 in.) above the ^{63}Ni-coated coupons (at the contact of the cutie pie) as a function of the thickness of the electroplated nickel.

3. SUMMARY OF ELECTROPLATED NICKEL ON LARGE COUPONS

A total of 71 coupons was electroplated with an average weight of 33.7 ± 5.8 mg nickel. Of these coupons, 3 were too heavy (>10%), 2 were rejected for poor quality of the nickel electroplate, and 14 were too light. The 14 light coupons were subjected to a second plating to achieve the desired thickness; 13 of those were within the desired weight limit, and 1 was too heavy. Finally, 64 good-quality plates were obtained with a mean nickel content of 35.3 ± 1.5 mg. The amounts of nickel plated on the coupons can be summarized as follows:

	Amount of nickel (mg)
On large coupons	2516.6
On small coupons	60.6
Total plated	2577.2

4. CONCLUSIONS AND RECOMMENDATIONS

The procedure described here proved to be practical and produced the desired results. The use of a somewhat higher concentration of nickel in the plating solution (by a factor of 2 to 10) may have resulted in more efficient plating (less time-consuming) with comparable material losses. No problems were encountered when a repeated plating was necessary in order to achieve the desired thickness.

5. ACKNOWLEDGMENT

The efforts of J. A. Tompkins during the initial period of this project are gratefully acknowledged.

6. REFERENCES

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