Essential Readings in Light Metals: Electrode Technology for Aluminum Production.
Edited by Alan Tomsett and John Johnson.
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DESIGN OF HIGHLY RELIABLE POT LININGS

J.M. PEYNEAU

Aluminium Pechiney LRF - BP 114

73300 Saint Jean de Maurienne - France

Lining reliability is measured by the life of the cathode. To obtain a good cathode life, a lining must be resistant to infiltrations, resistant to liquid products erosion and to fluorinated and sodium products impregnation (the "Rapoport effect").

These properties are obtained by a suitable pot lining design and more generally an adequate pot design, together with stable pot operation.

The main points of consideration are :

i) Pot thermal balance, shell mechanical design, cathode carbon selection and cathode block rodding, supported by mathematical models.

ii) Stable pot operation, cathode preheating and start-up.

The cathode life experienced with the 175/180 kA ALUMINIUM PECHINEY pot technology is discussed. To date the oldest pots of this generation are approaching nine years old.

INTRODUCTION

One of the main factors influencing the metal production cost and subsequently the profitability of an aluminium electrolysis pot is the life of the pot lining. The lining life depends on the manufacture and construction of the pot lining, the design characteristics of the pot and the way in which the potline is operated.

The development of mathematical models and criteria for pot lining construction and potline operation has made it possible to obtain pot lining life very seldom achieved to date (greater than 3 000 days).

A lining must be resistant to infiltration, resistant to liquid products erosion and be able to undergo, without deterioration, impregnation by fluorinated and sodium products.

This makes it necessary to have not only high quality construction materials, good construction techniques, suitable cathode bar rodding conditions but also correct lining design within a rigid pot shell, a stable thermoelectric and magnetohydrodynamic regime and finally good preheating, start-up conditions and operation of the pots.

In this presentation three important factors for obtaining a reliable pot lining will be reviewed. These are :

i) Minimising the "Rapoport effect".

ii) Cathode rodding quality.

iii) Stability of the pot.

MINIMISING THE "RAPOPORT EFFECT"

In 1957 RAPOPORT and SAMOILENKO (1) demonstrated the action of electrolysis bath on carbon cathodes. This phenomenon, known as the "Rapoport effect", results in an expansion of the cathode block by sodium and fluorinated products penetration.

Further details of the laboratory measurement technique for the "Rapoport effect" determination will not be covered however the major parameters influencing this phenomenon are listed and discussed below (2 to 7).

i) Cathode carbon characteristics.

ii) Bath temperature

iii) Cryolite ratio.

iv) Current density.

v) Mechanical stress on the cathode carbon.

vi) Current variations and interruptions.

Influence of the Cathode Carbon Characteristics

The characteristics of the carbon used in the cathode blocks are mainly influenced by :

i) Maximum baking temperature during manufacture of the cathode (Figure 1).

ii) The original structure of the carbon (Figure 2).

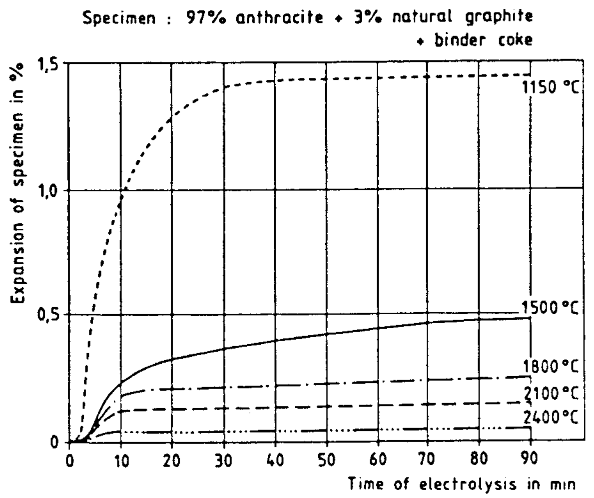

Figure 1 - Cathodic expansion curves for gas-calcined anthracite samples heat-treated at different temperatures (holding time 3h) (4).

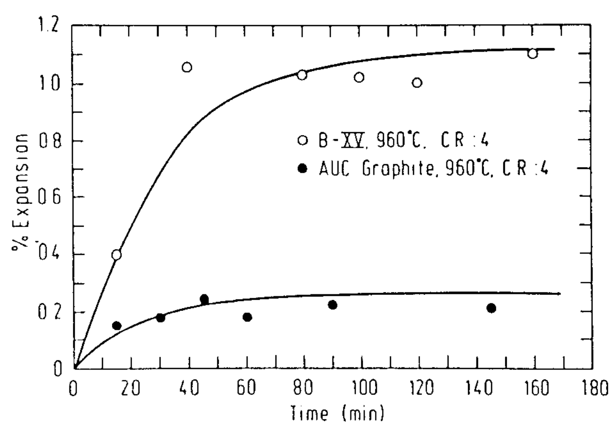

Figure 2 - Expansion of AUC graphite and a commercial cathode material, B-XV, during aluminium electrolysis (7).

Carbon can be classified by its response to the "Rapoport effect" in an increasing order as follows :

GRAPHITE < CALCINED ANTHRACITE < CALCINED FOUNDRY COKE < CALCINED PETROLEUM COKE

Influence of Bath Temperature

A decrease of bath temperature and therefore of the cathode block temperature results in an increase in the "Rapoport effect".

Influence of the Cryolite Ratio

A decrease of the cryolite ratio (NaF/AlF_3 mole ratio) which means an increase in weight percentage of excess AlF_3, results in substantial reductions in the "Rapoport effect" kinetics and the final result obtained (Figure 3).

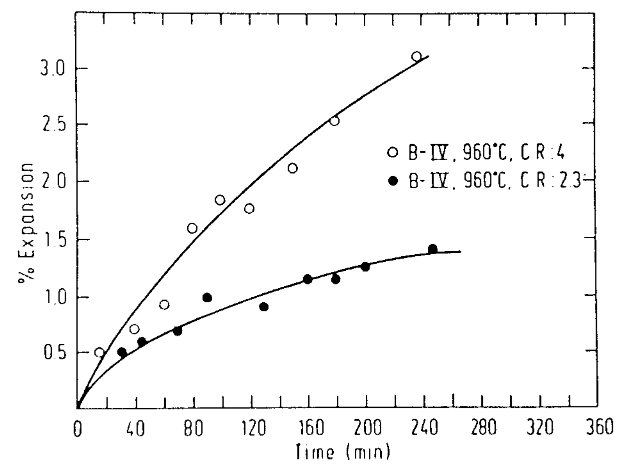

Figure 3 - Expansion of the cathode material, B-IV, during aluminium electrolysis at two different cryolite ratios (7).

In the operation of industrial pots, temperature and bath composition are not independent but the influence of temperature is predominant (Table 1.)

Table 1

Excess AlF_3 weight %	Bath Temperature °C	"Rapoport effect" deformation %
5.28	963	0.90
9.62	963	0.76
5.28	997	0.74
9.62	997	0.71

Table 1 - Laboratory "Rapoport effect" measurements for the same cathode carbon with various excess AlF_3 bath compositions and bath temperatures.

These laboratory tests show that for a given lower temperature, the "Rapoport effect" deformation decreases by a greater percentage when increasing the percentage of excess AlF_3, than for a given higher temperature.

Influence of Current Density

Increasing the current density results in an acceleration of the "Rapoport effect" kinetics (Figure 4).

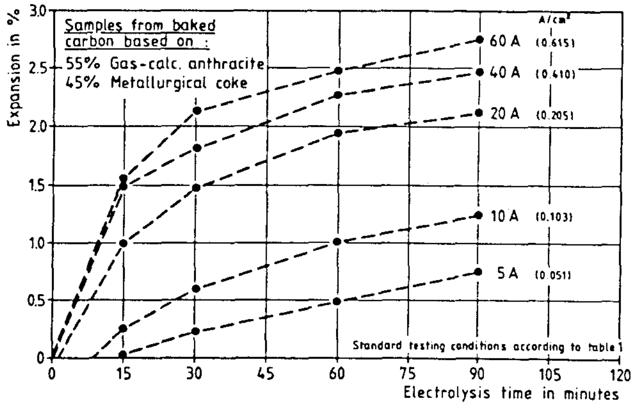

Figure 4 - Expansion of the carbon cathode during electrolysis in the testing cell at different cathodic current densities (4).

Influence of the Mechanical Stress on the Cathode Carbon

The application of a load to a carbon sample reduces the response to "Rapoport effect" in the direction of the applied load, both in the rate of response and the final result obtained (Figure 5). Mechanical stress increases the "Rapoport effect" response in the perpendicular direction to the load.

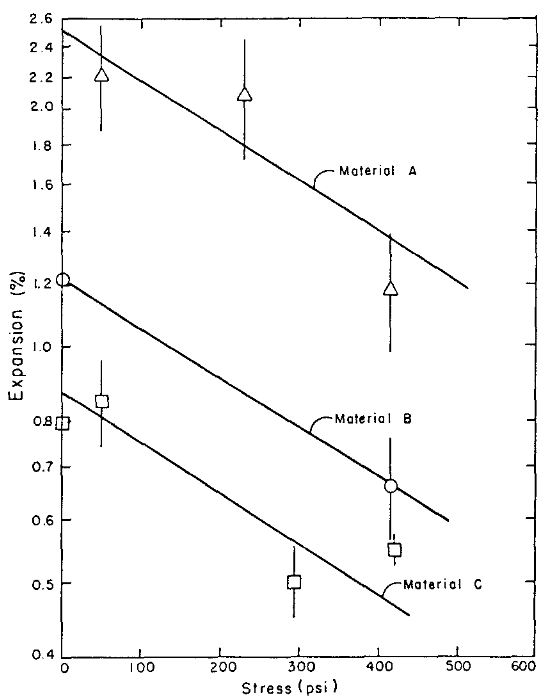

Figure 5 - Effect of stress on cathodic swelling of carbon (2).

In the electrolysis pot the stresses created by the expansion of the cathode carbon against the rigid pot shell tend to reduce the "Rapoport effect" in the longitudinal direction of the cathode blocks.

Extruded blocks have higher "Rapoport effect" in the direction of extrusion due to anisotropy. The pot shell constraint and the resulting stress reduce this "Rapoport effect".

Influence of Current Variations and Interruptions

Laboratory experiments have demonstrated that current failures accelerate "Rapoport effect" kinetics. The expansion of the cathode may be partly reversible but the remnant deformations will accumulate at each cycle, thereby resulting in a faster ageing as a consequence of cyclical fatigue.

In Summary

The influences referred to above do not act independently of each other. Therefore limiting the "Rapoport effect" requires consideration of all possible interactions together with economic constraints.

Selection of a cathode block with a demonstrated relatively low "Rapoport effect" is the first criterion. Some anthracite blocks meet this requirement. Depending on economic constraints it is also possible to select cathode blocks containing graphite aggregate (semi graphitic blocks) or those which have been heat treated to graphitize the entire block (graphitized blocks). If semi graphitic or graphitized blocks are used it may be necessary to adjust the thermal design of the pot to cope with the higher thermal and electrical conductivity of such blocks.

The second important criterion is the pot shell rigidity. The pot shell must be sufficiently rigid to maintain the pot cavity seal-tightness, (this will also depend upon the lining paste, refractory and insulation material quality) and to apply a stress to the hot and impregnated block in order to reduce the "Rapoport effect".

A mathematical model developed by ALUMINIUM PECHINEY allows the design of the pot shell, including the steel plate thickness, and ribbing that is needed to obtain the desired stiffness and to minimise the pot shell bowing and plastic deformation.

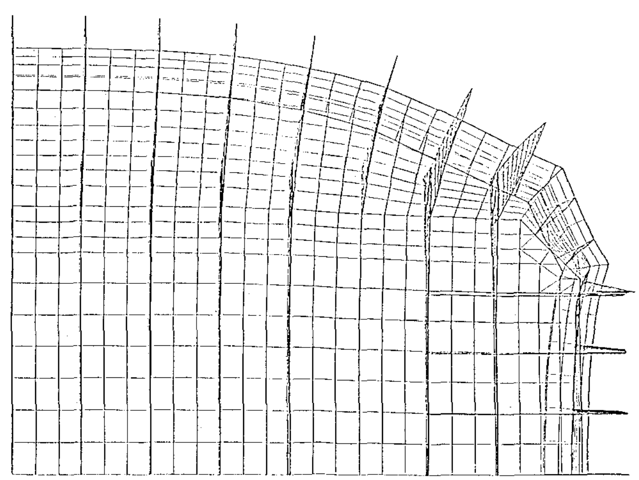

Figure 6 - Model simulation of pot shell deformation

CATHODE RODDING QUALITY

During the assembling of cathode bars into the cathode blocks with cast iron, the blocks are subjected to thermal stresses leading to the formation of cracks. This results in an increase in the electrical resistivity of the blocks, a decrease in the mechanical resistance and facilitates the penetration by liquid products and subsequent chemical impregnation.

ALUMINIUM PECHINEY has developed a mathematical model which allows the preparation of a 3 dimensional map of the stresses and deformation of the cathode block during the rodding operation (8).

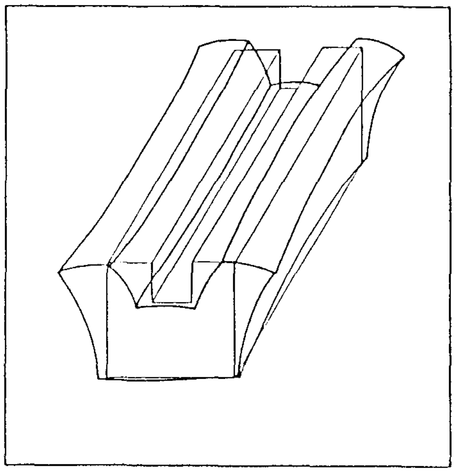

Figure 7 - Deformation of the cathode block during the rodding operation of the cathode bar (multiplied by 100) (8).

For a given type of cathode block the model allows the optimisation of the rodding procedure to prevent cracks. It is possible to establish the preheating procedures for the block and the bar before rodding and to determine if pre-stressing of the block is required.

STABILITY OF THE POT

Pot stability is defined by the thermal and magnetic balance resulting from the original design and the stable operation within an optimal and tightly specified range of operating parameters.

Thermal and Magnetic Balance

The design of high amperage modern pots has only been possible followings an improved knowledge of the magnetic fields within the electrolysis pot and being able to modify the design of the pot to accomodate these fields (9, 10, 11). Magnetic, electrical and magnetohydrodynamic mathematical models make it possible to design the busbar arrangement to obtain low velocities in the metal pad but sufficient velocities in the bath to permit dissolution of alumina. This correct pot design limits early cathode failures caused by preferential erosion of the cathode lining and avoids electrical imbalance allowing stable operation of the pot.

The thermoelectrical model developed by ALUMINIUM PECHINEY allows the calculation of :

i) The location of isotherms and equipotential positions particularly within the cathode lining.

ii) The position of the solid bath ridges.

iii) Heat flow.

iv) Horizontal electrical currents.

Therefore it is possible to design a pot with low horizontal electrical currents and to develop a cathode lining design, including specification of the various materials required, allowing stable pot operation with a long cathode life.

Stable Pot Operation

Smooth operation of a pot with tightly controlled operating parameters is as important for a long cathode life as are the aspects referred to in the previous section.

The principle of smooth operation is to be followed from the time a pot is placed into circuit with a gradual and closely regulated electrical preheat of the cathode and the anodes prior to start-up.

The pot start-up stage is crucial for the cathode impregnation and ultimately for the pot service life. Start-up is carried out with liquid bath maintaining a low pot voltage.

All the operating parameters are closely watched and tightly controlled within an optimal range during the period immediately following pot start-up (11, 12, 13). These include :

i) Anode/cathode distance.

ii) Alumina concentration in the bath.

iii) Bath composition.

iv) Bath temperature.

POT LIFE PERFORMANCE

Pot life performance of the 175/180 kA ALUMINIUM PECHINEY centre point-fed pots is discussed below.

The first industrial pot of this generation was started on 11 October, 1979 in Saint Jean de Maurienne, France, F line. Since then, close to 2 000 pots have been commissioned at 8 different smelters throughout the world.

The figures below refer to first generation pots at the oldest 6 smelters operating with such pots. This represents 1 562 pots with information obtained to 1 July, 1988.

Some potlines have experienced too few pot failures to permit valid statistical calculation of life expectancy. However the potlife results of the first two potlines using this technology are interesting to review.

In the first potline the potlife expectancy is greater than 3 000 days (48.3 % of the pots have failed and the average age of the remaining first generation pots is 3 137 days). In the second potline only 2.5 % of the pots have failed although the average life of the remaining pots is 2 413 days.

Figure 8 presents the age of the pots stopped for relining and the age of pots of first generation in operation. It also includes all types of cathode blocks and lining pastes which have been used in cathode construction.

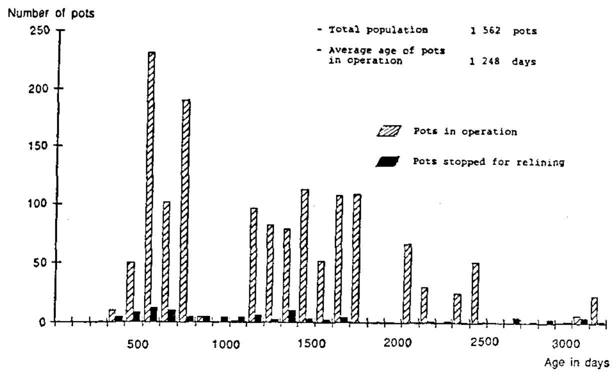

Figure 8 - Age of the pots stopped and in operation (all types of cathode blocks and lining pastes).

As of 1 July, 1988, 119 pots had been stopped representing 7.62 % of the total first generation pots in operation at the 6 smelters. The oldest pot still operating has a life of 3 184 days.

The design of the ALUMINIUM PECHINEY pot makes it possible to have a large choice of pot construction materials and therefore the pots commissioned have several types of cathode blocks.

Figure 9 shows the age of pots stopped and the age of pots in operation for the most used cathode block/lining paste combination. This cathode block is made from electro-calcined anthracite aggregate.

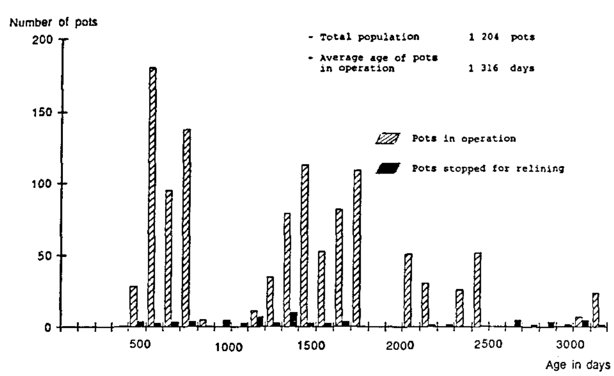

Figure 9 - Age of the pots stopped and in operation for the most common cathode block/lining paste combination.

As of 1 July, 1988, 81 pots have been stopped out of total of 1 204. This represent 6.73 % of the total population.

At this stage it is necessary to make a number of comments :

i) Several cathode blocks from various suppliers with different characteristics have been tested. Although the number of blocks tested is limited, it is possible to conclude that blocks with a high demonstrated "Rapoport effect" may fail prematurely and those with a low demonstrated "Rapoport effect" have an excellent life (see Figures 10, 11). Blocks with low "Rapoport effect" often contain graphite and their higher cost should be balanced with cathode life performance and observed cathode voltage drops.

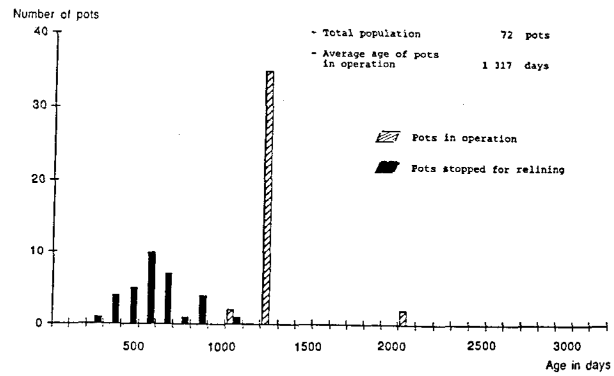

Figure 10 - Age of the pots stopped and in operation for blocks with high "Rapoport effect".

As of 1 July, 1988, 33 pots have been stopped out of a total of 72. This represents 45.83 % of the total population.

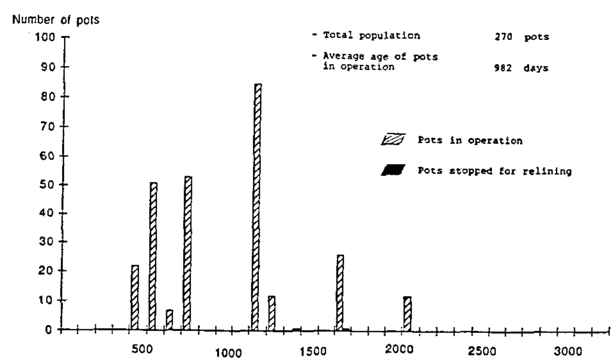

Figure 11 - Age of the pots stopped and in operation for blocks with low "Rapoport effect" (excluding the most commonly used blocks represented in Figure 9) combined with hot lining paste.

As of 1 July, 1988, 2 pots have been stopped (1 369 and 1 651 days old) out of a total of 270. This represents 0.74 % of the total population.

ii) One of the potlines among the 6 smelters included in this study suffered a very long power failure (8h30) during the first months of pot life. The pot life obtained to date on the pots which underwent this power failure appear not to be as long as that obtained at the other smelters. This is particularly so for pots containing blocks with high "Rapoport effect".

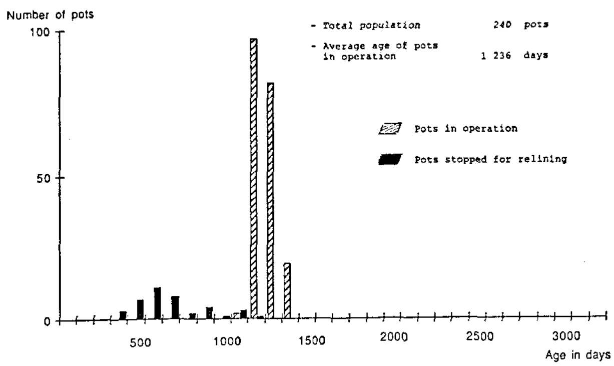

Figure 12 - Age of the pots stopped and in operation for a potline having suffered a long power shutdown during the first months of pot life. All types of blocks are included.

As of 1 July, 1988, 40 pots have been stopped out of a total of 240. This represents 16.67 % of the total population. 42.2 % of the pots using blocks with high "Rapoport effect" have been stopped.

It should be noted that information relating to this unusual episode has been included in Figures 8 to 11.

iii) A potline with an average pot age of almost 3 years underwent a controlled decrease in power (a reduction of 5.5 %) for a period of approximately 1 month and a temporary shutdown of 10 pots for a period of approximately 2 months without any apparent effect on the pot lining life.

As of 1 July, 1988, 2 pots have been stopped (at 2 174 days and 2 300 days) out of a total of 80 pots. The average age of the remaining pots in operation is 2 413 days.

iv) The episodes referred to in (ii) and (iii) above are abnormal situations and cannot be attributed to the normal operation of 175/180 kA ALUMINIUM PECHINEY electrolysis pots which have a demonstrated stable operation, obtained easily with suitable operating procedures.

Table 2 below summarizes the information presented in Figures 8 to 11.

Cathode type	Number of pots			Average age of pots in operation (days)	Age of oldest pot in operation (days)	Average life expectancy calculated (if possible) (days)
	Total	Stopped	In operation			
All cathode types	1 562	119	1 443	1 248	3 184	-
Pots with most commonly used cathode block	1 204	81	1 123	1 316	3 184	greater than 3 000 days
Pots with other low "Rapoport effect" cathode blocks	270	2	268	982	2 038	too few pots have failed
Pot with high "Rapoport effect" cathode blocks	72	33	39	1 317	2 050	1 500 to 2 000 days

Table 2 - Pot life performance of the 175/180 kA ALUMINIUM PECHINEY centre point-fed pots July 1988.

CONCLUSION

As of the 1 July, 1988 less than 8 % of the 175/180 kA designed, built and operated according to the procedures referred to in the text have failed.

The low failure rate experienced and differences in the age of pots in operation makes it difficult to accurately predict potlife expectancy.

In the two first potlines using this technology pot life expectancy has proven to be greater than 3 000 days.

ACKNOWLEDGEMENT

The author would like to thank the Plant Managers of Lochaber in Scotland, Karmøy in Norway, Baie Comeau and Becancour in Canada, Tomago in Australia and Saint Jean de Maurienne in France for providing the information on pot life experience and for allowing its publication.

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