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THE TITANIUM DECADE

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PREFACE

This memorandum contains the text of a talk given at the ninth annual Titanium Symposium held in conjunction with the Congress of the American Society of Metals at Detroit, Michigan, in October 1961. Footnotes have been added and a few changes have been made in the text itself in the process of preparing the paper for publication.

The talk was based on recent research into the development of titanium metal as an instance of Government-industry co-operation in the advancement of basic technology. This research is part of a continuing RAND study of problems of R and D policies and management.

The invitation to participate in the symposium was an opportunity to expose the early findings of the titanium study to searching discussion by an informed audience. A more complete report is planned which, profiting in large part from that discussion, will seek to indicate what lessons the history of titanium may suggest for the conduct of future programs aimed at stimulating rapid progress in military technology.

SUMMARY

The titanium development program illustrates inefficiencies inherent in Government-industry contractual arrangements aimed at rapid advances in basic technology. More than half the total cost of the program to the Government was the result of subsidizing the creation of a titanium metal industry. It is argued that such Government programs can be more efficient in the future if they recognize more specifically and are aimed more directly at the technological objective, and if the contracts with industry contain more direct rewards for research and development work as such (rather than indirect rewards in the form of production orders).

CONTENTS

I. INTRODUCTION

Technical people have been interested in titanium because it is titanium, because its remarkable qualities are exciting to metallurgists, and because they early saw in it a promise of new products filling previously unsatisfied needs. Moreover, their interest and optimism have been justified to the extent that the technological birth pangs of titanium have been passing, its economic growing pains have turned out fewer and shorter-lived than those of many predecessor metals, and the once young and sickly titanium industry is on the road to becoming healthy, achieving full flower, and settling down to a long and useful life.

My own interest, in a sense, is not in titanium at all -- or, more accurately, it is in titanium only incidentally. My main interest is in finding out what makes for rapid advances in basic technology. This is a subject about which there are more opinions than there is evidence, so that I thought it might be useful to see what could be learned from examination of some actual cases of rapid technological advance. Titanium has been such a case -- hence my interest in titanium.

Some of my remarks will be critical. Yet the criticisms will be made in the face of my own conviction that the achievements of the titanium program were impressive -- so much so that I was led to study titanium as an instance of rapid technological advance. What I shall be criticizing, then, is not the players, but the rules of the game. There has grown up in this country a pattern of Government-industry co-operation in the advancement of technology that often forces programs into channels that are not efficient. The outstanding characteristic of this pattern is that the normal reward for industrial R and D effort is a production contract, so that there is no adequate mechanism for the Government to buy only R and D from industry, without committing itself to procurement.

This pattern is quite clearly exemplified by the history of titanium development, as I shall try to indicate. It is this pattern, the rules of this game, that I have found interesting. It is an interesting game despite the fact that those who play it may themselves not like the rules -- as I think they often do not. I am not therefore suggesting that anyone involved in the titanium program did not do his best, given the rules and the terms of the contracts that were in force. What I am suggesting is that fundamental changes in the way the game itself is played, in the kinds of contracts that are entered into, could yield enhanced returns in the future.

It took sixteen years -- 1942 to 1958 -- to bring titanium from a paint pigment to a useful structural metal. As nearly as I can figure it out, the cost of doing so was about $200 million to the Government and almost as much more to private industry, for a total not far short of a half a billion dollars.* These statements may involve some over-simplifications. One can argue that the extractive metallurgy of titanium extends

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*The figure for private investment is an estimate given in Titanium: Part Product, Part Cause, New York, 1960 (privately printed). The figure for cost to the Government is based on information given in the Report of the Attorney General (on titanium), May 9, 1957, and in the Materials Advisory Board Report MAB-47-SM, General Review of the Titanium Metal Industry, February 14, 1958. Direct cost to the Government of approximately $190 million can be broken down as follows: R and D, about $55 m.; net cost to the Government as a result of commitments to purchase sponge, about $71 m.; inventory losses from stockpile acquisitions, about $64 m. These are, it should be emphasized, estimates, and may be on the low side. The cost of the Government's indirect subsidy to industry, represented by certificates authorizing rapid tax amortization of about $30 m. worth of plant, is not included in this total. Nor does the total include Department of Defense expenditures for the purchase of titanium mill products that went into operational hardware. I am indebted to my colleague Gene H. Fisher at RAND for indispensable assistance in arriving at the relevant figures.

back to Hunter in the early 1900's and even earlier. Others have argued that the investment was far greater, and that the true figure is very large and may never be known accurately. I think, nevertheless, that most people would argue that the modern period of titanium development began in the year 1942, and I have sought a cost figure conservative enough to command at least ball-park agreement among all who have an interest in arising at a just estimate of what the titanium program cost.

The first third of the sixteen years -- approximately -- went to establishing the pilot-plant feasibility of the Kroll process by the Bureau of Mines. The cost of the Bureau of Mines' work, of course, was not remotely a third of the total cost. I have found it impossible to arrive at a reliable figure, but I have the impression (which no one has disputed) that it is really insignificant -- perhaps a half of 1 per cent of the total cost.

The following ten years -- roughly from 1948 to 1958 -- saw the scaling-up of the Bureau of Mines' methods to production-plant size, the improvement and refinement of those methods in many important respects, and the development of at least first-cut melting and fabrication procedures. (It was not until the sheet-rolling program got underway that melting and fabrication began to get the full attention they deserved.) Those ten years also witnessed the creation of industrial production capacity far in excess of what the requirements were discovered to be at the end of that time.

The decade 1948-1958 involved virtually all the costs. About 20 million of the private dollars went into research and development (whatever that may include) and the rest went into plant. Of the Government money, about 55 million dollars -- perhaps more if we add work done in Government laboratories supported by their own appropriated funds -- bought R and D, and the balance was made up mainly of inventory losses resulting from guarantees to producers to purchase sponge and from additional purchases of sponge for stockpiling purposes.

The big question that needs to be answered is whether the very large cost to the Government of developing the technology of titanium is typical of the expected costs of advancing basic technology generally. If the answer to this question is yes, I think the country is in trouble. Either we'll go broke buying technology, or -- what is more likely -- we won't buy nearly as much technology as we'll need for national defense and industrial growth. I believe, however, that the answer to the question is no -- that the extremely high costs of titanium development were due to circumstances that obscured the proper function and goals of programs designed to advance technology. I should like to review some of these circumstances and goals and to explore ways in which future basic technology programs can perhaps be conducted more efficiently from the point of view of the Government. (Let me make quite clear, parenthetically, that by the term "efficiency" I mean getting maximum return for a given expenditure. The word does not relate to success by other criteria. I have little quarrel with the accomplishments of the titanium program, as I have said. My objection is that it cost too much.)

II. ADVANCING TECHNOLOGY OR "BUYING" AN INDUSTRY?

It is clear that the 200 million Government dollars bought not only titanium technology, but also in large part, a titanium industry -- a far larger titanium industry, from the point of view of production capacity, than was needed to produce the material that was actually used in operational military aircraft.* It is often argued that the titanium industry is a good thing, and that its brightening prospects for the future justify its creation. I am not inclined to dispute that judgment. I agree that the country is better off for having the titanium industry than it would be without it. On the other hand, I am inclined to argue that the Government does not need to buy an industry every time it wants to advance technology. At least I hope it doesn't. This means that I think it would have been possible, at least in principle, to buy the technology without buying the industry, and to do so therefore at considerably reduced cost.

Would this have been possible in fact? It would be easy to say that it would -- too easy. It would be easy to add up the recorded R and D expenditures, to say that the technology cost well under a hundred million dollars and the rest therefore bought an industry, to argue that the Bureau of Mines' pilot plant operation at Boulder City should have been continued and perhaps expanded somewhat, and that major investments in industrial support programs should have been postponed until it was clear that a good product was available and that there was a firm demand for it.

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*I shall henceforth, in speaking of costs, mean only direct costs to the Government as outlined in the preceding footnote. I shall not concern myself with the private industrial investment, although I think it should be noted that that investment is not likely to have been nearly so large as it was except for Government assistance of the sort already indicated.

But there are many pitfalls to such an oversimplified view. First, it is not at all clear what the phrase "R and D" means as a category of expenditure. It has tended to include a full range of activities from studying the atomic structure of pure iodide titanium to learning how to bend a sheet of 6-4 alloy to a specific aerodynamic design. So-called research contracts were sometimes awarded for the virtually sole purpose of encouraging a buildup of production capacity and industrial experience. Conversely, many of the most important technological advances came in the course of normal production, and were therefore never charged to R and D at all. Even so careful and conscientious a group as that at Battelle's Defense Materials Information Center has been unable to offer a fully consistent and reliable picture of titanium R and D expenditures, and I certainly do not expect to succeed where they have been unable to. The picture is inherently fuzzy and irrecoverable, so that it would be foolhardy to argue simply that the technology cost this much and the industrial capacity cost that much, and that the first was justified and the second wasteful.

A second complication centers around frequent misunderstanding of the so-called breadboard-model or pilot-plant stage of technological development. It is perfectly possible, for example, to solve many of the aerodynamic problems of the B-70 by putting a scale model into a supersonic wind tunnel, but it is not possible to solve the problem of melting big titanium ingots without actually melting big titanium ingots in large furnaces that use a lot of sponge. Melting small ingots in experimental furnaces that use a little sponge won't do it, because the problem is to melt big ingots. And big ingots and big furnaces for experimental purposes cost just as much as big ingots and big furnaces for production purposes.

There were several times during the titanium decade when going to industrial-scale equipment and production-size quantities was clearly dictated by technical reasons alone.

Another example is the famous hydrogen problem. It would have been perfectly possible in principle to devise means for reducing the hydrogen content of titanium ingots long before assembly-line failures forced the issue. Why, then, wasn't it done? It was not done, partly because there was no obvious reason to suspect the deleterious effects of hydrogen before the failures, and partly, according to at least one of the metallurgists intimately involved in that particular history, because there were not at the time routine measuring instruments and procedures reliable enough to flag the danger in advance. Failure to anticipate problems in science and engineering research is not an exception; it is the rule. This was one case where failure in the factory spurred a return to the laboratory to improve the product. The return and the improvement probably would have been indefinitely delayed but for earlier decisions to go from pilot plant to factory before all the technical uncertainties were resolved. It would be highly unrealistic to argue that the step was unjustified.

The general argument that industrial-scale operations were inextricably and necessarily involved in the advancement of titanium technology, therefore, carries considerable weight, even though some of the specific arguments are less convincing. I have been told, for example, that titanium technology would not now be where it is without benefit of the industry because many of the important technical milestones were reached in the experimental shops of private companies. I take it, however, that individual scientists and engineers accomplished these advances, that many of these individuals went to the industry from Government and non-industrial laboratories, and that the accident of their location at the time the advances were made is not particularly relevant.

Similarly, it follows from the importance of fabrication and quality-control techniques to titanium technology that, given the lack of appropriate Government facilities, industry had to be involved. What does not follow is that quite so many companies and quite so much production had to be involved. I see nothing that would have prevented the Government from signing R and D contracts -- at significantly less than the cost of buying industrial production capacity -- with a sponge producer, a melting and fabricating plant, and, say, an aircraft and engine company to carry the exploration of titanium right through to the production prototype stage. If advancing technology had been the principal objective, there would have been ample time at that point to worry about quantity production and procurement.*

But advancing technology was not the principal objective. At least it never was again after the Bureau of Mines interlude during the first half of the 1940's. Publication of the two epochal Bureau of Mines' papers in 1946 released a complexity of activities by diverse organizations amounting during the next decade to a veritable maze of conflicting interests, directions, predictions, and motivations. It is little wonder

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*I should here emphasize that I am criticizing unnecessary duplication of production capacity. Duplication of R and D programs in the sense of pursuing simultaneously alternative approaches to the solution of difficult technical problems is often not only necessary, but essential to efficient conduct of research.

that the goal of pushing titanium technology was diluted in the process, and made incidental to broader, more ambitious, far more expensive -- but not clearly more sensible -- objectives.

Statements of military requirements during the years 1951-1957 had by far the greatest diversionary effect. Rapid production of titanium sponge was made literally synonymous with national survival. Titanium was the wonder metal. Absolutely nothing else could substitute for it in the next generation of high-Mach-number military airplanes. Failure to produce, stockpile, and fabricate ever-increasing quantities of it, at almost any cost, was tantamount to giving in to the Russians without a fight. In fairness to the Department of Defense it must be said that it was indulged in these views by the Congress, by the Aircraft Industries Association, by the titanium companies (with perhaps an occasional exception) and even -- to some degree -- by the various titanium advisory committees, at least until the storm clouds began clearly to threaten. It seems indeed in retrospect that all who had a hand in titanium, no matter how remotely, were, for a period of years, in the grip of a widespread hypnosis.

I repeat, however, that this was not self-hypnosis in the sense that good judgment took a holiday. Rather was judgment constrained by the pressures that had been built up in the situation, and by the absence of alternative ways of achieving what should have been the central objective of advancing titanium technology. The hypnosis in short was largely inherent in what I have called the rules of the game, and in the fact that you can't change the rules while you're running for the goalpost.

We know today that if the nation does not survive it will not be because we don't have titanium airplanes. Titanium is a good and useful metal, whose full potentialities have probably yet to be tapped, but it seems no more wonderful than many others. We know that it is not unique and irreplaceable. For most of the applications originally conceived, the newer stainless steels seem as of now to be giving titanium very stiff competition, although it is only fair to recall that titanium has proved itself exactly suited to its purposes in some particular applications, such as the fan disks and blades of aircraft turbofan engines. We know that titanium has a future, but we know that this future will be quite different from the future predicted for it ten years ago. That initially predicted future -- except for some parts of engines and edges of air-frames -- has not come to pass.

We know these things today. Did we or could we have known them ten years ago? We obviously did not, and it is idle to speculate whether we could have. The important point is rather that we did not know -- and could not have known -- that these things would not be so. And since, as everybody now agrees, titanium has in fact not delivered fully on its early promise as a military aircraft material, there is no time during the entire decade that anyone could have known that it would.

I am sure I do not need to emphasize the many uncertainties that inevitably attach to any scientific or engineering development. Not only was titanium no exception, but it was perhaps subject to even more than the normal number of uncertainties by reason of its temperamental characteristics. The production of sponge is a discrete, discontinuous process that poses problems of removal and cleaning. Melted sponge creates difficulties of handling reminiscent of breakfast marmalade on the morning newspaper. Overheat the material, and it will attract everything in sight including the kitchen sink. Fabrication poses problems by comparison to which making steel parts, I am told, is as easy as cutting paper dolls. There is precious little, indeed, that has not been uncertain about titanium.

I think one can marvel at the ingenuity and inventiveness that have been solving these problems one by one, and still wonder at the expanding production goals, at the exorbitant drain on funds, at the general euphoria that existed before the problems were solved. What were the factors that contributed to management of the titanium program as if the uncertainties were certain and the future clear?

The major factor, as I have suggested, was that the military requirements were optimistic and exaggerated with respect both to the characteristics expected of the metal and the quantities likely to be needed. This is not a new phenomenon. For reasons that I and some of my colleagues at RAND have detailed elsewhere, military R and D requirements have often been stated as if they were detailed production specifications or operational plans. They depreciate technological uncertainties and they assume that the course of the future is known. In the case of titanium, it was assumed that manufactured mill products would display all the qualities promised by laboratory samples, that they would do so by a specified date, that the costs would be bearable, and that predicted weapon needs would persist unchanged. None of these assumptions proved justified, which led to the 1957 crash -- to the sudden cut of stated military needs to a third of what they had been.

The lesson for the future is to hedge enthusiasm with a realization of technological uncertainty, to keep requirements in line with technical progress, and to explore alternatives in case the white hope of the moment falters. Who can say confidently that a part of the money that the Government spent on titanium would not have brought greater returns than it did at the time if it had been devoted instead to accelerated research on the newer stainless steels?

Another factor in the precipitous pursuit of titanium may have been the Korean War. This factor -- if it was one -- is difficult to evaluate and there is little I can say about it with confidence. Titanium -- the wonder metal -- might have appealed as a gimmick to ease the pressure of the war. The answer to that is that the next war will be fought with forces in being, that mobilization base has lost much of its erstwhile importance, and that the objective is to buy ever-advancing technology rather than tonnages to put in storehouses.

A third factor in the titanium adventure was the readiness of the industry to multiply itself under Government prodding. I do not mean to criticize the industry. No one could reasonably have expected it to turn down contracts offered by the Government. By the same token, Government must be quite clear what it wants to buy before it signs a contract, and it must offer the kind of contract that will buy it what it wants, not something else. Here, perhaps is where the confusion of goals is clearest. The Government apparently decided to buy an industry in the expectation that the industry would provide the technology. Perhaps it should rather have decided what was needed in the way of advancing technology and then negotiated for the <u>services</u> of industry to supplement its own research and development efforts.

It may be that the various suggestions I have made so far boil down to a need for self-conscious recognition by the Government of the specific goal of advancing technology, and for a reasoned plan to achieve that goal. The interests of basic technology have tended in the past to get lost in the pursuit of two other objectives. There is on the one hand support of basic research which, according to academic tradition, should be unfettered, generous, and rarely examined for probable practical payoff. On the other hand, there is the development of the specific hardware system. Here the exact objective is spelled out in detail, and we are supposed to proceed toward it with mathematical certainty unencumbered by empirical contingencies. This is pure folklore, of course. The real job of advancing basic technology, in the meanwhile, gets relegated to ad hoc efforts, with ad hoc funding, on a crash basis. This, largely, has been the story of titanium.

I should like to emphasize again that I don't think that any individual, organization, or institution is to blame for this. Rather was the titanium story like a Greek tragedy, in which there are no villains, but in which the fatal flaw is somehow inherent in the situation. It is the situation I quarrel with -- the ground rules, as I put it earlier. There are times when we desperately need industrial R and D efforts without being too sure about production. I think the titanium decade was such a time, and I think such times will come more frequently in the future. For such times, we need an alternative to the present pattern, an alternative that will enable industry and Government to co-operate fully and wholeheartedly in advancing technology without requiring either to pursue the goal circuitously or to seek its rewards indirectly.

What is the alternative? I think it is to define the function of advancing basic technology, to distinguish it from academic research, from system development, and from hardware production, to survey new and promising possibilities as they appear, to plan programs with the objective of demonstrating operational and economic feasibility, and to allocate funds according to what has been demonstrated by experimental tests rather than on the basis of imprecise or premature objectives. Had the development of titanium been pursued as part of such a planned effort, I am sure it would have cost far less, and I suspect that its progress would have been surer. I even suspect that the development of the titanium industry might have issued from such a program with far fewer upsetting ups and downs.