III

PROPITIATION

[1981 – 1991]

Let craft, ambition, spite,
Be quenched in Reason's night,
Till weakness turn to might,
Till what is dark be light,
Till what is wrong be right!

Lewis Carroll

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Seekers

A minor tussle over my services occurred at this time, between ISRO, which was a little hesitant to relieve me, and DRDO, which wanted to take me in. Many months went by, and many letters were exchanged between ISRO and DRDO; and meetings were held in the secretariats of the Defence R&D establishment and the Department of Space to precipitate a mutually convenient course of action. Meanwhile, Prof. Ramanna retired from the office of the Scientific Advisor to Defence Minister. Dr VS Arunachalam, till then Director of the Defence Metallurgical Research Laboratory (DMRL) in Hyderabad, succeeded Prof. Ramanna. Dr Arunachalam was known for his confidence, and he cared little for the intricacies and nuances of the scientific bureaucracy. Meanwhile, I understand that the Defence Minister at that time, R Venkataraman discussed the matter of my taking over the missile laboratory with Prof. Dhawan. Prof. Dhawan also seemed to be waiting for a decisive step at the highest level in the Defence Ministry. Overcoming the niggling doubts that had caused delays over the past year, the decision to appoint me Director, DRDL was finally taken in February, 1982.

Prof. Dhawan used to visit my room in the ISRO headquarters and spend many hours in evolving space launch vehicle projects. It was a great privilege to work with such a great scientist. Before I left ISRO, Prof. Dhawan asked me to give a talk on the Space Programme Profile in India by the year 2000. Almost the entire ISRO management and staff attended my talk, which was by way of a farewell meeting.

I had met Dr VS Arunachalam in 1976, when I visited DMRL in connection with the aluminium alloy investment casting for the SLV inertial guidance platform. Taking it as a personal challenge, Dr Arunachalam had the investment casting, the first of its kind in the country, made in the incredibly short time of two months. His youthful energy and enthusiasm never failed to amaze me. This young metallurgist had within a short span of time lifted the science of metal-making to the technology of metal-forming and then to the art of alloy development. With a tall and elegant figure, Dr Arunachalam was like an electrically charged dynamo himself. I found him an unusually friendly person with a forceful manner, as well as an excellent working partner.

I visited DRDL in April 1982 to acquaint myself with my potential work site. The Director of DRDL then, SL Bansal, took me around and introduced me to the senior scientists in the laboratory. DRDL was working on five staff projects and sixteen competence build-up projects. They were also involved in several technology-oriented activities with a view to gain lead time for the development of indigenous missile systems in future. I was particularly impressed by their efforts on the twin 30-ton Liquid Propellant Rocket Engine.

Meanwhile, Anna University, Madras, conferred the honorary degree of Doctor of Science on me. It had been nearly twenty years since I had acquired my degree in aeronautical engineering. I was happy that Anna University had recognized my efforts in the field of rocketry, but what pleased me most was the recognition of the value of our work in academic circles. To my delight, the honorary doctorate degree was awarded at a convocation presided over by Prof. Raja Ramanna.

I joined DRDL on 1 June, 1982. Very soon, I realized that this laboratory was still haunted by the winding up of the Devil missile project. Many excellent professionals had not yet recovered from the disappointment. People outside the scientific world may find it difficult to comprehend how a scientist feels when the umbilical cord to his work is suddenly snapped, for reasons totally alien to his understanding and interests. The general mood and work tempo at DRDL reminded me of Samuel Taylor Coleridge's poem The Rime of the Ancient Mariner:

Day after day, day after day,
We stuck, nor breath, nor motion;
As idle as a painted ship
Upon a painted ocean.

I found almost all my senior colleagues living with the pain of dashed hopes. There was a widespread feeling that the scientists of this laboratory had been cheated by the senior officials in the Ministry of Defence. It was clear to me that the burial of the Devil was essential for the rise of hope and vision.

When about a month later, Admiral OS Dawson, then the Chief of Naval Staff, visited DRDL, I used it as an opportunity to make a point with my team. The Tactical Core Vehicle (TCV) project had been hanging fire for quite some time. It was conceived as a single core vehicle with certain common subsystems to meet the requirements of the services for a quick reaction Surface-to-Air Missile, an anti-radiation Air-to-Surface Missile which could be launched from helicopters or fixed wing aircraft. I emphasized the sea-skimming role of the core vehicle to Admiral Dawson. I focussed not on its technical intricacies, but on its battlefield capabilities; and I highlighted the production plans. The message was loud and clear to my new associates—do not make anything which you cannot sell later and do not spend your life on making one thing only. Missile development is a multi-dimensional business—if you remain in any one dimension for a long time, you will get stuck.

My initial few months at DRDL were largely interactive. I had read at St. Joseph's that an electron may appear as a particle or wave depending on how you look at it. If you ask a particle question, it will give you a particle answer; if you ask a wave question, it will give you a wave answer. I not only described and explained our goals, but also made them an interplay between our work and ourselves. I still recall quoting Ronald Fischer at one of the meetings, "The sweetness we taste in a piece of sugar is neither a property of the sugar nor a property of ourselves. We are producing the experience of sweetness in the process of interacting with the sugar."

Very good work on a Surface-to-Surface missile with a vertical rise-turn straight line climb-ballistic path had been done by that time. I was astonished to see the determination of the DRDL workforce, who, in spite of the premature winding up of their earlier projects, were eager to go ahead. I arranged reviews for its various subsystems, to arrive at precise specifications. To the horror of many old-timers in DRDO, I started inviting people from the Indian Institute of Science, Indian Institutes of Technology, Council for Scientific and Industrial Research, Tata Institute of Fundamental Research, and many other educational institutions where related experts could be found. I felt that the stuffy work centres of DRDL needed a breath of fresh air. Once we opened the windows wide, the light of scientific talent began to pour in. Once more, Coleridge's Ancient Mariner came to mind: "Swiftly, swiftly flew the ship,\ Riding gently the oncoming tide."

Sometime in the beginning of 1983, Prof. Dhawan visited DRDL. I reminded him of his own advice to me almost a decade ago: "You have to dream before your dreams can come true. Some people stride towards whatever it is that they want in life; others shuffle their feet and never get started because they do not know what they want—and do not know how to find it either." ISRO was lucky to have had Prof. Sarabhai and Prof. Dhawan at the helm—leaders who elucidated their goals, made their missions larger than their lives, and could then inspire their entire workforce. DRDL had not been so lucky. This excellent laboratory played a truncated role that did not reflect its existing or potential capabilities or even fulfill the expectations in South Block. I told Prof. Dhawan about the highly professional, but slightly bewildered team I had. Prof. Dhawan responded with his characteristic broad smile which could be interpreted in any way one chose.

In order to accelerate the pace of R&D activities at DRDL, it was imperative that decisions on vital scientific, technical and technological problems be taken quickly. Throughout my career I had zealously pursued openness in scientific matters. I had seen from very close quarters the decay and disintegration that go with management through closed-door consultations and secret manipulations. I always despised and resisted such efforts. So the first major decision which we took was to create a forum of senior scientists where important matters could be discussed

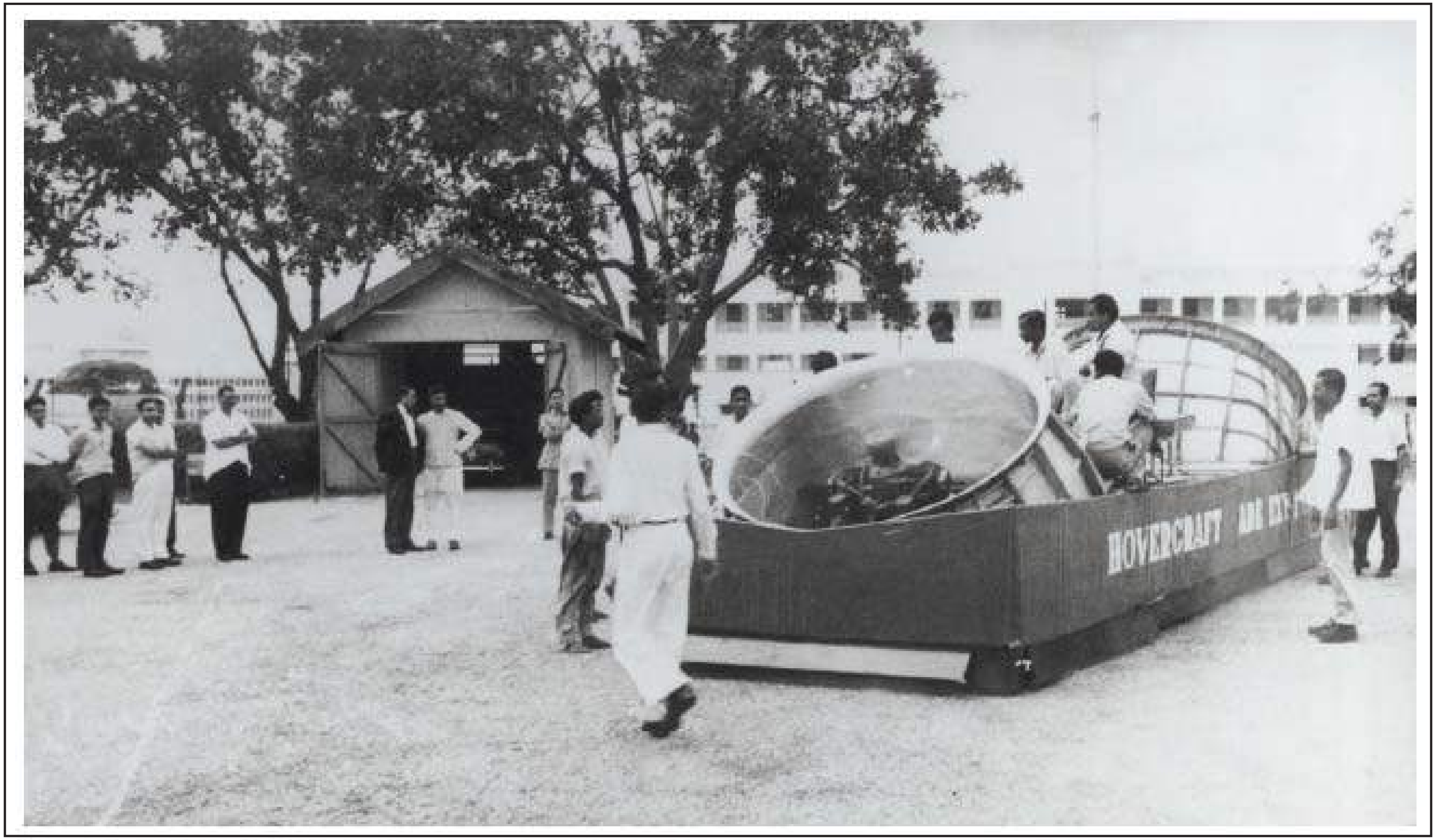

Plate 9 **The twin-engine indigenous hovercraft prototype Nandi developed at ADE, Bangalore. As inventor and pilot, I took my rightful place at the controls.**

Plate 10 The Christian community in Thumba very graciously gave up this beautiful Church to house the first unit of the Space Research Centre.

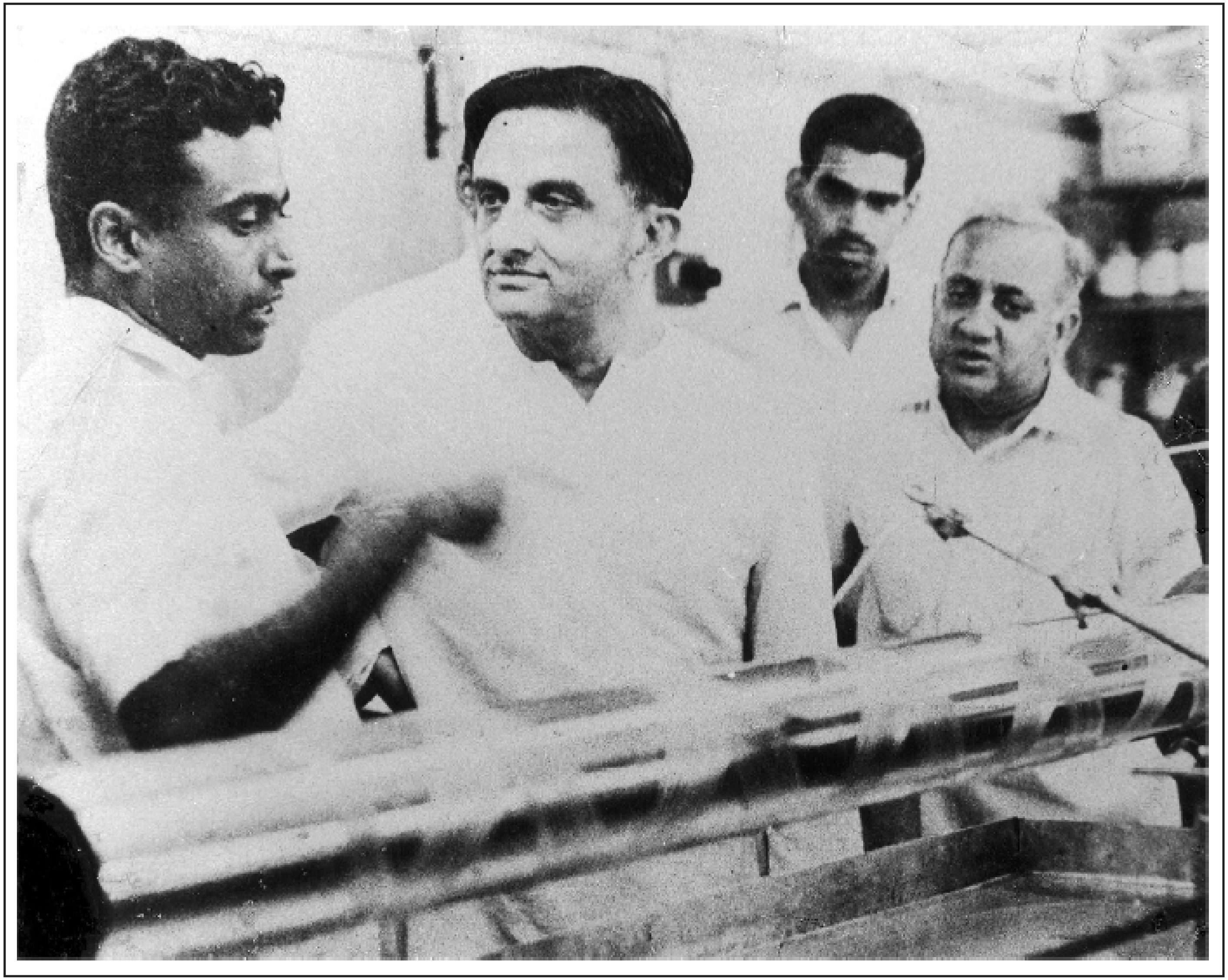

Plate 11 With Prof Vikram Sarabhai, a great visionary and the master planner behind India's Missile Development programme, at Thumba

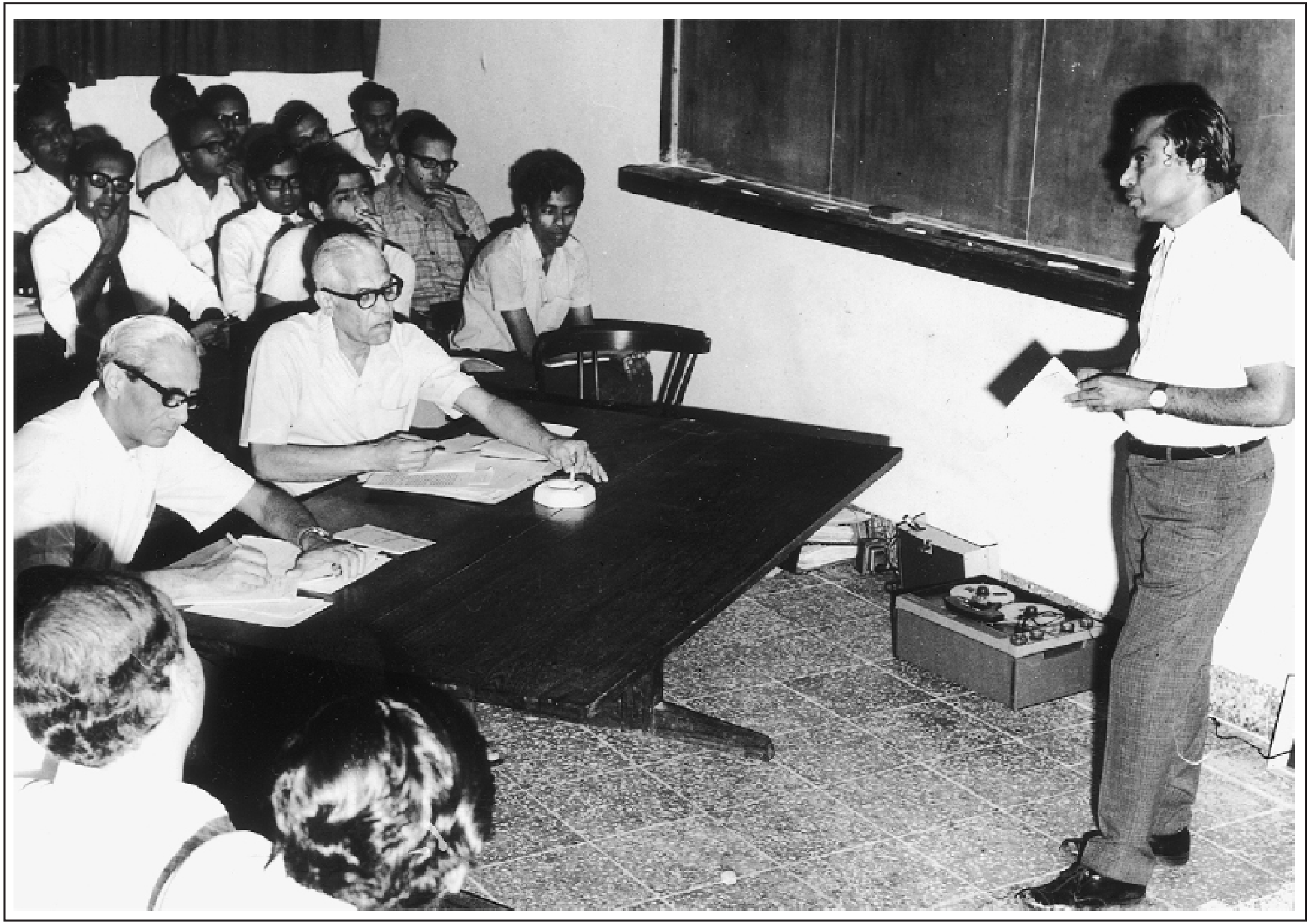

Plate 12 Two gurus of Indian Space Research who mentored and gently guided the young scientists – Prof Satish Dhawan and Dr Brahm Prakash – at one of the SLV-3 review meetings.

Plate 13 A presentation by a member of my SLV-3 team. In an unusual move, I made each of them present their portion of the work—my idea of project management.

Plate 14 Dr Brahm Prakash inspecting SLV-3 in its final phase of integration. He helped me deal with subsequent frustrations in its launching and consoled me when I was at my lowest ebb.

Plate 15 Prof Satish Dhawan and I explaining SLV-3 results to Prime Minister Indira Gandhi.

Plate 16 **SLV-3 on the launch pad. This gave us many anxious moments!**

Plate 17 **Receiving the Padma Bushan from Dr Neelam Sanjeeva Reddy, then President of India.**

Plate 18 Successful launch of Prithvi, the surface-to-surface weapons system.

Plate 19 Agni on the launch pad, my long-cherished dream.

You said it

By LAXMAN

Nothing to be discouraged! We have postponed it again because we want to be absolutely certain!

Plate 20 One of the cartoons in the media after the failure of the first two Agni launches.

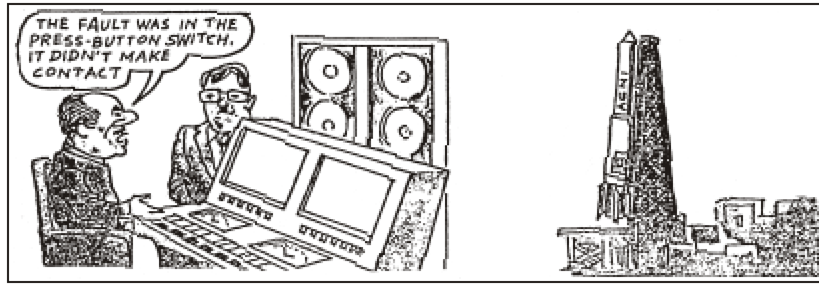

Plate 21 Many a slip between the cup and the lip... .

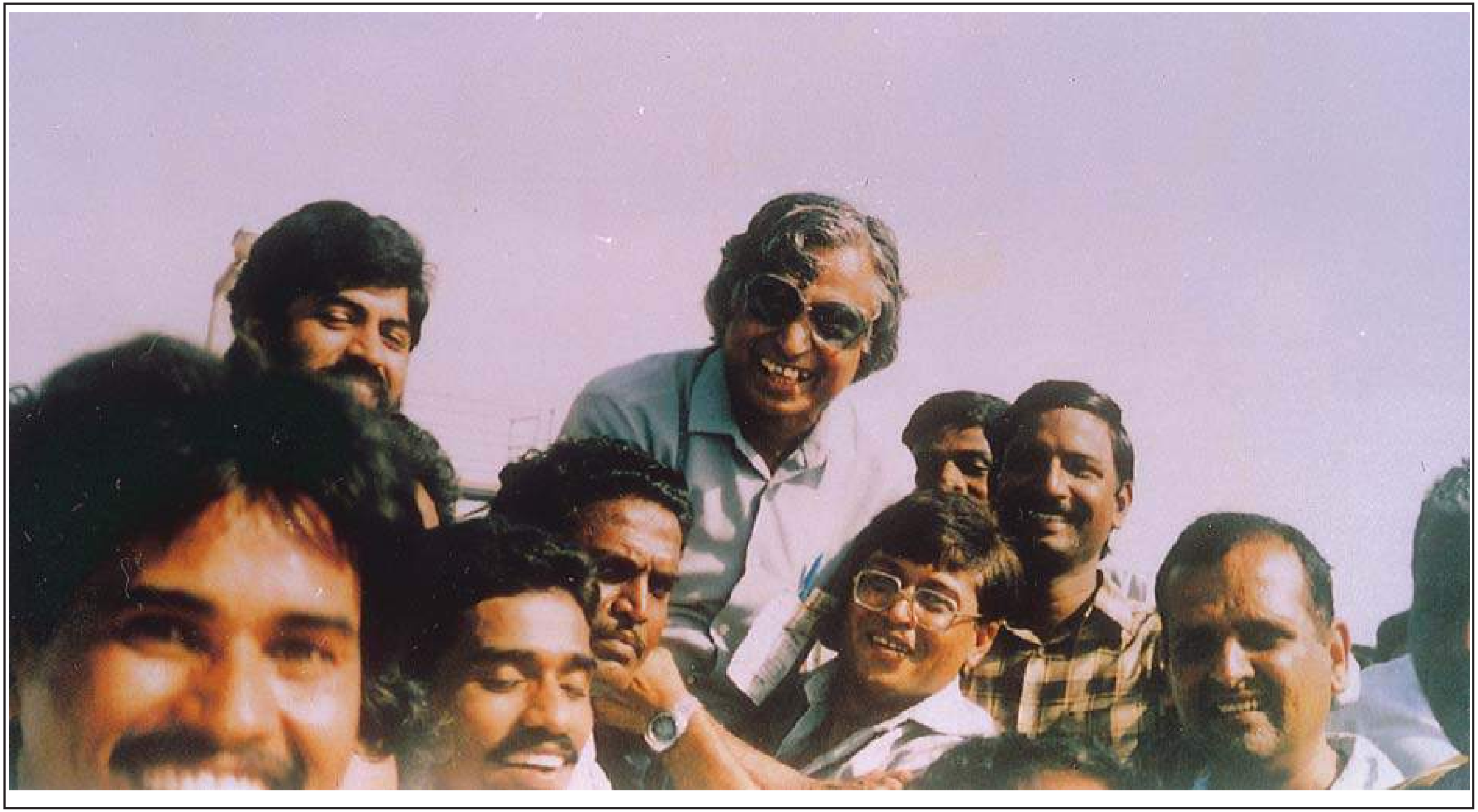

Plate 22 Being carried by a jubilant crowd after the successful launch of Agni.

Plate 23 Receiving the Bharat Ratna from President KR Narayanan.

Plate 24 With three Service Chiefs. To my left is Admiral VS Shekhawat, on his right is General BC Joshi, and Air Chief Marshal SK Kaul.

and debated as a collective endeavour. Thus, a high level body called the Missile Technology Committee was formed within DRDL. The concept of management by participation was evoked and earnest efforts were made to involve middle-level scientists and engineers in the management activities of the laboratory.

Days of debate and weeks of thinking finally culminated in the long-term 'Guided Missile Development Programme'. I had read somewhere, "Know where you are going. The great thing in the world is not knowing so much where we stand, as in what direction we are moving." What if we did not have the technological might of the Western countries, we knew we had to attain that might, and this determination was our driving force. To draw up a clear and well-defined missile development programme for the production of indigenous missiles, a committee was constituted under my chairmanship. The members were ZP Marshall, then the Chief of Bharat Dynamics Limited, Hyderabad, NR Iyer, AK Kapoor and KS Venkataraman. We drafted a paper for the perusal of the Cabinet Committee for Political Affairs (CCPA). The paper was given its final shape after consulting the representatives of the three Defence Services. We estimated an expenditure of about Rs 390 crores, spread over a period of twelve years.

Development programmes often get stuck by the time they reach the production stage, mainly because of lack of funding. We wanted to get funds to develop and produce two missiles—a low-level quick reaction Tactical Core Vehicle and a Medium Range Surface-to-Surface Weapon System. We planned to make a surface-to-air medium range weapon system with multi-target handling capability during the second phase. DRDL had been known for its pioneering work in the field of anti-tank missiles. We proposed to develop a third generation anti-tank guided missile having 'fire-and-forget' capabilities. All my colleagues were pleased with the proposal. They saw an opportunity to pursue afresh activities initiated long ago. But I was not entirely satisfied. I longed to revive my buried dream of a Re-entry Experiment Launch Vehicle (REX). I persuaded my colleagues to take up a technology development project to generate data for use in the design of heat shields. These shields were required for building up capability to make long-range missiles in the future.

I made a presentation in the South Block. The presentation was presided over by the Defence Minister of the time R Venkataraman, and attended by the three Service Chiefs: General Krishna Rao, Air Chief Marshal Dilbagh Singh and Admiral Dawson. The Cabinet Secretary, Krishna Rao Sahib, Defence Secretary, SM Ghosh and Secretary, Expenditure, R Ganapathy were present. Everyone seemed to have all sorts of doubts—about our capabilities, about the feasibility and availability of required technological infrastructure, about the viability, the schedule and cost. Dr Arunachalam stood by me like a rock throughout the entire question-answer session. Members were skeptical and apprehensive of drift—which they felt was common among scientists. Although some questioned our ambitious proposal, everyone, even the doubting Thomases, were very excited about the idea of India having her own missile systems. In the end, we were asked by Defence Minister Venkataraman to meet him in the evening, about three hours later.

We spent the intervening time working on permutations and combinations. If they sanctioned only Rs 100 crores, how would we allocate it? Suppose they gave us Rs 200 crores, then what would we do? When we met the Defence Minister in the evening, I had a hunch we were going to get some funds at any rate. But when he suggested that we launch an integrated guided missile development programme, instead of making missiles in phases, we could not believe our ears.

We were quite dumbfounded by the Defence Minister's suggestion. After a long pause, Dr Arunachalam replied, "We beg for time to rethink and return, Sir!" "You come back tomorrow morning please," the Defence Minister replied. It was reminiscent of Prof. Sarabhai's zeal and vision. That night, Dr Arunachalam and I laboured together on reworking our plan.

We worked out some very important extensions and improvements in our proposal, taking all the variables, such as design, fabrication, system integration, qualification, experimental flights, evaluation, updating, user trials, producibility, quality, reliability, and financial viability into account. We then integrated them into a single function of total accountability, in order to meet the needs of the country's armed forces with an indigenous endeavour. We worked out the concepts of design, development, production concurrency and proposed the participation of user and inspection agencies right from the drawing-board stage. We also suggested a methodology to achieve state-of-the-art systems after all the years of developmental activities. We wanted to deliver contemporary missiles to our Services and not some outdated inventory of weapons. It was a very exciting challenge that had been thrown to us.

By the time we finished our work, it was already morning. Suddenly, at the breakfast table, I remembered that I was to attend my niece Zameela's wedding at Rameswaram that evening. I thought it was already too late to do anything. Even if I could catch the Madras flight later in the day, how would I reach Rameswaram from there? There was no air link between Madras and Madurai from where I could board the evening train to Rameswaram. A pang of guilt dampened my spirits. Was it fair, I asked myself, to forget my family commitments and obligations? Zameela was more like a daughter to me. The thought of missing her wedding because of professional preoccupations at Delhi was very distressing. I finished breakfast and left for the meeting.

When we met Defence Minister Venkataraman and showed him our revised proposal, he was visibly pleased. The proposal of the missile development project had been turned overnight into the blueprint of an integrated programme with far-reaching consequences. It would have wide-ranging technological spinoffs, and was exactly what the Defence Minister had had in mind the previous evening. Notwithstanding the great respect I had for the Defence Minister, I was not really sure if he would clear our entire proposal. But he did. I was absolutely delighted!

The Defence Minister stood up, signalling that the meeting was over. Turning to me he said, "Since I brought you here, I was expecting you to come up with something like this. I am happy to see your work." In a split second, the mystery surrounding the clearance of my appointment as Director DRDL in 1982 was cleared. So it was Defence Minister Venkataraman who had brought me in! Bowing in thanks, I turned towards the door when I heard Dr Arunachalam telling the Minister about Zameela's wedding being scheduled for that evening at Rameswaram. It amazed me that Dr Arunachalam should bring up this matter before the Minister. Why would a person of his stature, sitting in

the all-powerful South Block, be concerned about a wedding which was to take place on a far-flung island in a small house on Mosque Street?

I have always had a high regard for Dr Arunachalam. He has together with a command over language as he displayed on this occasion, an uncanny presence of mind. I was overwhelmed when the Defence Minister located an Air Force helicopter doing sorties between Madras and Madurai later in the day to take me to Madurai as soon as I disembarked at Madras from the regular Indian Airlines flight, which was leaving Delhi in an hour's time. Dr Arunachalam told me, "You have earned this for your hard work of the last six months."

Flying towards Madras, I scribbled on the back of my boarding pass:

Who never climbed the weary league –
Can such a foot explore
The purple territories
On Rameswaram's shore?

The Air Force helicopter landed close to the Indian Airlines aircraft as soon as it arrived from Delhi. Within the next few minutes I was on my way to Madurai. The Air Force commandant there was kind enough to take me to the railway station, where the train to Rameswaram was just about to roll out of the platform. I was in Rameswaram well in time for Zameela's wedding. I blessed my brother's daughter with a father's love.

The Defence Minister put up our proposal before the Cabinet and saw it through. His recommendations on our proposal were accepted and an unprecedented amount of Rs 388 crores was sanctioned for this purpose. Thus was born India's prestigious Integrated Guided Missile Development Programme, later abbreviated to IGMDP.

When I presented the government sanction letter before the Missile Technology Committee at DRDL, they were enthused with fire and action. The proposed projects were christened in accordance with the spirit of India's self-reliance. Thus the Surface-to-Surface weapon system became Prithvi ("the Earth") and the Tactical Core Vehicle was called Trishul (the trident of Lord Shiva). The Surface-to-Air area defence system was named as Akash ("sky") and the anti-tank missile project Nag ("Cobra"). I gave the name Agni ("Fire") to my long cherished dream of REX. Dr Arunachalam came to DRDL and formally launched the IGMDP on 27 July 1983. It was a great event in which every single employee of DRDL participated. Everybody who was somebody in Indian Aerospace Research was invited. A large number of scientists from other laboratories and organizations, professors from academic institutions, representatives of the armed forces, production centres, and inspection authorities, who were our business partners now, were present on this occasion. A closed-circuit TV network had to be pressed into operation to ensure proper communication between the participants for we had no single place to accommodate all the invitees. This was the second most significant day in my career, next only to 18 July 1980, when the SLV-3 had launched Rohini into the earth's orbit.

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11

Stewards

The launch of the IGMDP was like a bright flash on the Indian scientific firmament. Missile Technology had been considered the domain of a few selected nations in the world. People were curious to see how, with what India had at that point of time, we were going to achieve all that was promised. The magnitude of the IGMDP was really unprecedented in the country and the schedules projected were quite quixotic by the norms and standards prevailing in the Indian R&D establishments. I was fully aware that obtaining sanction for the programme could at best be seen as only ten per cent of the work done. To get it going would be quite a different matter altogether. The more you have, the more there is to maintain. Now that we had been given all the necessary money and freedom to proceed, I had to take my team forward and fulfill the promises I had made.

What would be needed to realise this missile programme, from the design to the deployment stages? Excellent manpower was available; money had been sanctioned; and some infrastructure also existed. What was lacking then? What else does a project need to succeed apart from these three vital inputs? From my SLV-3 experience, I thought I knew the answer. The crux was going to be out mastery over missile technology. I expected nothing from abroad. Technology is a group activity and we would need leaders who could not only put their heart and soul into the missile programme, but also carry along with them hundreds of other engineers and scientists. We knew we had to be prepared to encounter numerous contradictions and procedural absurdities that were prevalent in the participating laboratories. We would have to counteract the existing attitudes of our public sector units, which believed that their performance would never be tested. The whole system—its people, procedures, infrastructure—would have to learn to extend itself. We decided to achieve something that was way beyond our collective national capability and I, for one, had no illusions about the fact that unless our teams worked on the basis of proportion or probability, nothing would be achieved.

The most remarkable thing about DRDL was its large pool of highly talented people, many of whom were, unfortunately, full of egotism and rebelliousness. Unfortunately, they had not even accumulated enough experience to make them confident about their own judgement. On the whole, they would discuss matters very enthusiastically, but would finally accept what a select few said. They would unquestioningly believe in outside specialists.

A particularly interesting person I met in DRDL was AV Ranga Rao. He was very articulate and had an impressive personality. His usual garb consisted of a red neck-tie with a checked coat and loose trousers. He would wear this in the hot climate of Hyderabad, where even a long-sleeved shirt and shoes are considered an avoidable inconvenience. With his thick white beard and a pipe clamped between his teeth, there was a certain aura around this extremely gifted, but rather egocentric individual.

I consulted Ranga Rao on revamping the existing management system to achieve an optimum utilization of human resources. Ranga Rao had a series of meetings with the scientists sharing our vision of developing indigenous missile technology and explaining the different aspects of the IGMDP. After prolonged discussions, we decided to reorganize the laboratory into a technology-oriented structure. We needed to accommodate a matrix type of structure for the execution of various activities needed for the projects. In less than four months, four hundred scientists began to work on the missile programme.

During this period, the most important task before me was the selection of the Project Directors to lead individual missile projects. We had a very large pool of talent. In fact, it was a market of plenty. The question was whom to pick—a go-getter, a planner, a maverick, a dictator or a team man? I had to get the right type of leader who could clearly visualize the goal, and channelise the energies of his team members who would be working at different work centres in pursuit of their own individual goals.

It was a difficult game, some rules of which I had learnt while working on ISRO's high priority projects for two decades. The wrong choice would jeopardise the entire future of the programme. I had a detailed discussion with a large number of prospective scientists and engineers. I wanted these five Project Directors to train another twenty-five project directors and team leaders of tomorrow.

Many of my senior colleagues—naming them would be unfair, because it could be only my imagination—tried to befriend me during this period. I respected their concern for a lonely man, but avoided any close contacts. Through loyalty to a friend one can be easily led into doing something that is not in the best interests of the organization.

Perhaps the main motive behind my isolation was my desire to escape from the demands of relationships, which I consider very difficult in comparison to making rockets. All I desired was to be true to my way of life, to uphold the science of rocketry in my country and to retire with a clean conscience. I took quite some time and did a lot of hard thinking to decide who should lead the five projects. I examined the working styles of many scientists before making my decision. I think some of my observations may interest you.

A basic aspect of a person's working style is how he plans and organizes tasks. At one extreme is the cautious planner, who carefully spells out each step before making any move. With a sharp eye for what can possibly go wrong, he tries to cover all contingencies. At the other end is the fast mover, who weaves and dodges without a plan. Inspired by an idea, the fast mover is always ready for action.

Another aspect of a person's working style is control—the energy and attention devoted to ensuring that things happen in a certain way. At one extreme is the tight controller, a strict administrator with frequent checkpoints. Rules and policies are to be followed with religious fervour. At the opposite end are those who move with freedom and flexibility. They have little patience for bureaucracy. They delegate easily and give their subordinates wide latitude for movement. I wanted leaders who tread the middle path, those who could control without stifling dissent or being rigid.

I wanted men who had the capability to grow with possibilities, with the patience to explore all possible alternatives, with the wisdom to apply old principles to new situations; people with the skill to negotiate their way forward. I wanted them to be accommodating, to be willing to share their power with others and work in teams, delegating good jobs, assimilating fresh opinions, respecting intelligent people, and listening to wise counsel. They would have to be able to sort out things amicably, and take responsibility for slip-ups. Above all, they should be able to take failure in their stride and share in both success and failure.

My search for someone to lead the Prithvi project ended with Col VJ Sundaram who belonged to the EME Corps of the Indian Army. With a post-graduate degree in Aeronautical Engineering and expertise in mechanical vibrations, Sundaram was head of the Structures Group at DRDL. I found in him a readiness to experiment with new ways of resolving conflicting points of view. He was an experimenter and innovator in team work. He had an extraordinary capability for evaluating alternative ways of operating. He would suggest moving forward into new terrains that could lead to a solution which had not been perceived earlier. Though a particular goal might be clear to a project leader, and he may be capable of giving adequate directions for accomplishing it, there can be resistance from subordinates if the goal makes no sense to them. Therein lies the importance of a leader who provides effective work directions. I thought the Project Director of Prithvi would be the first to make decisions with production agencies and the armed forces, and Sundaram would be the ideal choice to see that sound decisions were taken.

For Trishul, I was looking for a man who not only had a sound knowledge of electronics and missile warfare, but who could also communicate the complexities to his team in order to promote understanding and to earn his team's support. I found in Cmde SR Mohan, who sailed into Defence R&D from the Indian Navy, a talent for detail and an almost magical power of persuasion.

For Agni, my dream project, I needed somebody who would tolerate my occasional meddling in the running of this project. In RN Agarwal I found the right person. He was an alumnus of MIT with a brilliant academic record and had been managing the Aeronautical Test Facilities at DRDL with keen professional acumen.

Due to technological complexities, Akash and Nag were then considered missiles of the future; their activities were expected to peak about half a decade later. Therefore, I selected the relatively young Prahlada and NR Iyer for Akash and Nag. Two other young men, VK Saraswat and AK Kapoor were made deputies to Sundaram and Mohan respectively.

In those days, there was no forum in DRDL where issues of general importance could be openly discussed and decisions debated. Scientists, it must be remembered, are basically emotional people. Once they stumble, it is difficult for them to pull themselves together. Setbacks and disappointments have always been and always will be an inherent part of any career, even one in science. However, I did not want any of my scientists to face disappointments alone. I also wanted to ensure that none of them set their goals when they were at a low ebb. To avoid such eventualities a Science Council was created—a sort of panchayat where the community would sit together and take common decisions. Every three months, all scientists—juniors and seniors, veterans and freshers—would sit together and let off steam.

The very first meeting of the Council was eventful. After a spell of half-hearted enquiries and expressions of doubt, one senior scientist, MN Rao, shot a straight question: "On what basis did you select these five Pandavas (he meant the Project Directors)?" I was, in fact, expecting this question. I wanted to tell him that I found all these five Pandavas married to the Draupadi of positive thinking. Instead, I told Rao to wait and see. I had chosen them to take charge of a long-term programme where new storms would arise everyday.

Every tomorrow, I told Rao, will give opportunities to these enthusiastic people—the Agarwals, Prahladas, Iyers, and Saras-wats—to gain a fresh perspective on their goals and a strong hold on their commitments.

What makes a productive leader? In my opinion, a productive leader must be very competent in staffing. He should continually introduce new blood into the organization. He must be adept at dealing with problems and new concepts. The problems encountered by an R&D organization typically involve trade-offs among a wide variety of known and unknown parameters. Skill in handling these complex entities is important in achieving high productivity. The leader must be capable of instilling enthusiasm in his team. He should give appropriate credit where it is due; praise publicly, but criticize privately.

One of the most difficult questions came from a young scientist: "How are you going to stop these projects from going the Devil way?" I explained to him the philosophy behind IGMDP—it begins with design and ends in deployment. The participation of the production centres and user agencies right from the design stage had been ensured and there was no question of going back till the missile systems had been successfully deployed in the battlefield.

While the process of forming teams and organizing work was going on, I found that the space available at DRDL was grossly inadequate to meet the enhanced requirements of IGMDP. Some of the facilities would have to be located at a nearby site. The missile integration and checkout facility built during the Devil phase consisted only of a 120 sq. metre shed thickly populated with pigeons. Where was the space and the facility to integrate the five missiles which would arrive here shortly? The Environmental Test Facility and the Avionics Laboratory were equally cramped and ill-equipped. I visited the nearby Imarat Kancha area. It used to be the test range for anti-tank missiles developed by DRDL decades ago. The terrain was barren—there were hardly any trees—and dotted with large boulders typical of the Deccan plateau. I felt as if there was some tremendous energy trapped in these stones. I decided to locate the integration and check-out facilities needed for the missile projects here. For the next three years, this became my mission.

We drew up a proposal to establish a model high technology research centre with very advanced technical facilities like an inertial instrumentation laboratory, full-scale environmental and electronic warfare (EMI/EMC) test facilities, a composites production centre, high enthalpy facility, and a state-of-the-art missile integration and checkout centre. By any standards, this was a gigantic task. An altogether different brand of expertise, grit and determination were required to realise this project. Goals and objectives had already been decided upon. Now they had to be shared with a large number of people from various agencies, through the problem-solving and communication processes that the leader of the team must build and maintain. Who would be the most suitable person to do so? I saw almost all the required leadership qualities in MV Suryakantha Rao. Then, as a large number of agencies would participate in the creation of Research Centre Imarat (RCI), someone had to protect hierarchical sensitivities. I selected Krishna Mohan, who was in his mid-thirties, to complement Suryakantha Rao, who was in his late fifties at that time. Krishna Mohan would encourage involvement rather than relying on obedience and monitoring people at their workplaces.

According to the established procedure, we approached the Military Engineering Services (MES) for the RCI construction work. They said it would take five years to complete the task. The matter was discussed in depth at the highest level in the Ministry of Defence and a landmark decision to entrust the responsibility of building defence structures to an outside construction company was taken. We liaised with the Survey of India and the National Remote Sensing Agency for the inspection of the contour maps and for obtaining aerial photographs of the Imarat Kancha to prepare a layout for the approach roads and the location of the facilities. The Central Ground Water Board identified twenty locations amid the rocks to tap water. Infrastructure to provide 40 MVA power and 5 million litres of water per day was planned.

It was also at this time that Col SK Salwan, a mechanical engineer with boundless energy, joined us. In the final phase of construction, Salwan discovered an ancient place of worship among the boulders. It seemed to me that this place was blessed.

Now that we had started working on the design of the missile systems and development had already commenced for their integration and checkout, the next logical step was to look for a suitable site for the missile flight trials. With SHAR also in Andhra Pradesh, the search for a suitable site spread towards the eastern coastline and finally ended at Balasore in Orissa. A site along the north-eastern coast was identified for a National Test Range. Unfortunately the entire project ran into rough weather because of the political issues raised around the evacuation of people living in that area. We decided therefore to create an interim infrastructure adjacent to the Proof Experimental Establishment (PXE) at Chandipur in Balasore district of Orissa. A funding of Rs 30 crores had been given to construct the range, called the Interim Test Range (ITR). Dr HS Rama Rao and his team did an excellent job of working out innovative and cost-effective specifications for electro-optical tracking instruments, a tracking telescope system and an instrumentation tracking radar. Lt Gen RS Deswal and Maj Gen KN Singh took charge of creating the launch pad and range infrastructure. There was a beautiful bird sanctuary in Chandipur. I asked the engineers to design the test range without disturbing it.

Creating the RCI was perhaps the most satisfying experience of my life. Developing this centre of excellence of missile technology was akin to the joy of a potter shaping artifacts of lasting beauty from the mundane clay.

Defence Minister R Venkataraman visited DRDL in September 1983 to appraise himself of the activities of IGMDP. He advised us to list all the resources we needed to achieve our goals, overlooking nothing, and then include in the list our own positive imagination and faith. “What you imagine, is what will transpire. What you believe is what you will achieve,” he said. Both Dr Arunachalam and I saw in the horizon endless possibilities stretching out before IGMDP; and our enthusiasm proved infectious. We were excited and encouraged to see the best professionals in the country gravitating towards IGMDP. Who would not want to associate with a winner? The word had evidently got around that the IGMDP was a born winner.

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12

Workers

We were at a meeting laying down the targets for 1984, when news came of Dr Brahm Prakash’s death on the evening of 3 January at Bombay. It was a great emotional loss for me, for I had had the privilege of working under him during the most challenging period of my career. His compassion and humility were exemplary. His healing touch on the day of the failed SLV-E1 flight surfaced in my memory serving to deepen my sorrow.

If Prof. Sarabhai was the creator of VSSC, Dr Brahm Prakash was the executor. He had nurtured the institution when it most needed nourishment. Dr Brahm Prakash played a very important role in shaping my leadership skills. In fact my association with him was a turning point in my life. His humility mellowed me and helped me discard my aggressive approach. His humility did not consist merely in being modest about his talents or virtues, but in respecting the dignity of all those who worked under him and in recognizing the fact that no one is infallible, not even the leader. He was an intellectual giant with a frail constitution; he had a childlike innocence and I always considered him a saint among scientists.

During this period of renaissance at DRDL, an altitude control system and an on-board computer developed by P Banerjee, KV Ramana Sai and their team was almost ready. The success of this effort was very vital for any indigenous missile development programme. All the same, we had to have a missile to test this important system.

After many brainstorming sessions, we decided to improvise a Devil missile to test the system. A Devil missile was dis-assembled, many modifications made, extensive subsystem testing was done and the missile checkout system was reconfigured. After installing a make-shift launcher, the modified and extended range Devil missile was fired on 26 June 1984 to flight test the first indigenous Strap-down Inertial Guidance system. The system met all the requirements. This was the first and very significant step in the history of Indian missile development, which had so far been restricted to reverse engineering, towards designing our own systems. A long-denied opportunity was at last utilized by missile scientists at DRDL. The message was loud and clear. We could do it!

It did not take long for the message to reach Delhi. Prime Minister Indira Gandhi expressed her desire to personally apprise herself of the progress of the IGMDP. The entire organization was filled with an aura of excitement. On 19 July 1984, Shrimati Gandhi visited DRDL.

Prime Minister Indira Gandhi was a person with a tremendous sense of pride—in herself, in her work and in her country. I deemed it an honour to receive her at DRDL as she had instilled some of her own pride into my otherwise modest frame of mind. She was immensely conscious that she was the leader of eight hundred million people. Every step, every gesture, every movement of her hands was optimised. The esteem in which she held our work in the field of guided missiles boosted our morale immensely.

During the one hour that she spent at DRDL, she covered wide-ranging aspects of the IGMDP, from flight system plans to multiple development laboratories. In the end, she addressed the 2000-strong DRDL community. She asked for the schedules of the flight system that we were working on. “When are you going to flight test Prithvi?” Shrimati Gandhi asked. I said, “June 1987.” She immediately responded, “Let me know what is needed to accelerate the flight schedule.” She wanted scientific and technological results fast. “Your fast pace of work is the hope of the entire nation,” she said. She also told me that the emphasis of the IGMDP should be not only on schedule but also on the pursuance of excellence. “No matter what you achieve, you should never be completely satisfied and should always be searching for ways to prove yourself,” she added. Within a month, she demonstrated her interest and support by sending the newly appointed Defence Minister, SB Chavan, to review our projects. Shrimati Gandhi’s follow-up approach was not only impressive, it was effective too. Today, everyone associated with aerospace research in our country knows that excellence is synonymous with the IGMDP.

We had our home-grown, but effective, management techniques. One such technique was concerned with follow-up of project activities. It basically consisted of analysing the technical as well as procedural applicability of a possible solution, testing it with the work centres, discussing it with the general body of associates and implementing it after enlisting everybody’s support. A large number of original ideas sprung up from the grass root level of participating work centres. If you were to ask me to indicate the single most important managerial tactic in this successful programme, I would point to the pro-active follow-up. Through follow-up on the work done at different laboratories on design, planning, supporting services, and by the inspection agencies and academic institutions, rapid progress has been achieved in the most harmonious manner. In fact, the work code in the Guided Missile Programme Office was: if you need to write a letter to a work centre, send a fax; if you need to send a telex or fax, telephone; and if the need arises for telephonic discussions, visit the place personally.

The power of this approach came to light when Dr Arunachalam conducted a comprehensive status review of IGMDP on 27 September 1984. Experts from DRDO Laboratories, ISRO, academic institutions, and production agencies gathered to critically review the progress made and problems faced in the first year of implementation. Major decisions like the creation of facilities at Imarat Kancha and the establishment of a test facility were crystallized during the review. The future infrastructure at the Imarat Kancha was given the name of Research Centre Imarat (RCI), retaining the original identity of the place.

It was a pleasure to find an old acquaintance, TN Seshan, on the review board. Between SLV-3 and now, we had developed a mutual affection. However, this time as the Defence Secretary, Seshan's queries about the schedules and viability of financial propositions presented were much more pointed. Seshan is a person who enjoys verbally bringing adversaries to their knees. Using his sharp-edged humour, Seshan would make his opponents look ridiculous. Although he is prone to be loud and can turn argumentative on occasions, in the end he would always ensure maximization of all available resources towards a solution that was within implementation. At a personal level, Seshan is a very kind-hearted and considerate person. My team was particularly pleased to answer his questions about the advanced technology employed in the IGMDP. I still remember his uncanny curiosity about the indigenous development of carbon-carbon composites. And to let you into a small secret—Seshan is perhaps the only person in the world who enjoys calling me by my full name which contains 31 letters and five words—Avul Pakir Jainulabdeen Abdul Kalam.

The missile programme had been pursued concurrently and had partners in design, development and production from 12 academic institutions and 30 laboratories from DRDO, the Council of Scientific and Industrial Research (CSIR), ISRO and industry. In fact, more than 50 professors and 100 research scholars worked on missile-related problems in the laboratories of their respective institutes. The quality of work achieved through this partnership in that one year had given me tremendous confidence that any development task could be undertaken within the country so long as we have our focussed schedules. Four months before this review, I think it was during April–June 1984, six of us in the missile programme visited academic campuses and enlisted promising young graduates. We presented an outline of the missile programme before the professors and the aspiring students, about 350 of them, and requested them to participate. I informed the reviewers that we were expecting around 300 young engineers to join our laboratories.

Roddam Narasimha, then Director of the National Aeronautical Laboratory, used the occasion of this review to put up a strong case for technology initiative. He cited the experiences of the green revolution, which had demonstrated beyond doubt that if the goals were clear, there

was enough talent available in the country to tackle major technological challenges.

When India carried out its first nuclear explosion for peaceful purposes, we declared ourselves the sixth country in the world to explode a nuclear device. When we launched SLV-3 we were the fifth country to achieve satellite launch capability. When were we going to be the first or second country in the world to achieve a technological feat?

I listened carefully to the review members as they aired their opinions and doubts, and I learned from their collective wisdom. It was indeed a great education for me. Ironically, all through school, we were taught to read, write and speak, but never to listen, and the situation remains much the same today. Traditionally, Indian scientists have been very good speakers, but have inadequately developed listening skills. We made a resolution to be attentive listeners. Are engineering structures not built on the foundation of functional utility? Does technical know-how not form its bricks? And, are these bricks not put together with the mortar of constructive criticism? The foundation had been laid, the bricks baked, and now the mortar to cement our act together was being mixed.

We were working on the action plan that had emerged from the earlier month's review, when the news of Shrimati Gandhi's assassination broke. This was followed by the news of widespread violence and riots. A curfew had been imposed in Hyderabad city. We rolled up the PERT charts and a city map was spread out over the table to organize transport and safe passage for all employees. In less than an hour, the laboratory wore a deserted look. I was left sitting alone in my office. The circumstances of Shrimati Gandhi's death were very ominous. The memories of her visit barely three months ago further deepened my pain. Why should great people meet with such horrific ends? I recollected my father telling someone in a similar context: "Good and bad people live together under the sun as the black thread and the white are woven together in a cloth. When either one of the black or white thread breaks, the weaver shall look into the whole cloth, and he shall examine the loom also." When I drove out of the laboratory there was not a single soul on the road. I kept thinking about the loom of the broken thread.

Shrimati Gandhi's death was a tremendous loss to the scientific community. She had given impetus to scientific research in the country. But India is a very resilient nation. It gradually absorbed the shock of Shrimati Gandhi's assassination, although at the cost of thousands of lives and a colossal loss of property. Her son, Rajiv Gandhi, took over as the new Prime Minister of India. He went to the polls and obtained a mandate from the people to carry forward the policies of Mrs. Gandhi, the Integrated Guided Missile Development Programme being a part of them.

By the summer of 1985, all the groundwork had been completed for building the Missile Technology Research Centre at Imarat Kancha. Prime Minister Rajiv Gandhi laid the foundation stone of the Research Centre Imarat (RCI) on 3 August 1985. He appeared very pleased with the progress made. There was a child-like curiosity in him which was very engaging. The grit and determination displayed by his mother when she visited us a year ago was also present in him, although with a small difference. Madam Gandhi was a taskmaster, whereas Prime Minister Rajiv Gandhi used his charisma to achieve his ends. He told the DRDL family that he realised the hardships faced by Indian scientists and expressed his gratitude towards those who preferred to stay back and work in their motherland rather than go abroad for comfortable careers. He said that nobody could concentrate on work of this type unless he was free from the trivialities of daily life, and assured us that whatever necessary would be done to make scientists' lives more comfortable.

Within a week of his visit, I left for the USA with Dr Arunachalam on an invitation from the United States Air Force. Roddam Narasimha of National Aeronautical Laboratory and KK Ganapathy of HAL accompanied us. After finishing our work at the Pentagon in Washington, we landed in San Francisco on our way to Los Angeles to visit Northrop Corporation. I utilized this opportunity to visit the Crystal Cathedral built by my favourite author, Robert Schuller. I was amazed by the sheer beauty of this all-glass, four-pointed, star-shaped structure that is more than 400 feet from one point to another. The glass roof which is 100 feet longer than a football field seemed to float in space. This Cathedral has been built at the cost of several million dollars through donations organized by Schuller. "God can do tremendous things through the person who doesn't care about who gets the credit. The ego involvement must go," writes Schuller. "Before God trusts you with success, you have to prove yourself humble enough to handle the big prize." I prayed to God in Schuller's church to help me build a Research Centre at the Imarat Kancha—that would be my Crystal Cathedral.

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Triumphant

The young engineers, 280 to be precise, changed the dynamics of DRDL. It was a valuable experience for all of us. We were now in a position to develop, through these young teams, a re-entry technology and structure, a millimetric wave radar, a phased array radar, rocket systems and other such equipment. When we first assigned these tasks to the young scientists, they did not fully grasp the importance of their work. Once they did, they felt uneasy under the burden of the tremendous faith placed in them. I still remember one young man telling me, “There is no big shot in our team, how will we be able to break through?” I told him, “A big shot is a little shot who keeps on shooting, so keep trying.” It was astonishing to see how in the young scientific environment, negative attitudes changed to positive and things that were previously thought impractical began happening. Many older scientists were rejuvenated simply by being part of a young team.

It has been my personal experience that the true flavour, the real fun, the continuous excitement of work lie in the process of doing it rather than in having it over and done with. To return to the four basic factors that I am convinced are involved in successful outcomes: goal-setting, positive thinking, visualizing, and believing.

By now, we had gone through an elaborate exercise of goal-setting and enthused the young scientists about these goals. At the review meetings, I would insist that the youngest scientists present their team’s work. That would help them in visualizing the whole system. Gradually, an atmosphere of confidence grew. Young scientists started questioning senior colleagues on solid technical issues. Nothing daunted them, because they feared nothing. If there were doubts, they rose above them. They soon became persons of power. A person with belief never grovels before anyone, whining and whimpering that it’s all too much, that he lacks support, that he is being treated unfairly. Instead, such a person tackles problems head on and then affirms, ‘As a child of God, I am greater than anything that can happen to me’. I tried to keep the work environment lively with a good blend of the experience of the older scientists mixed with the skills of their younger colleagues. This positive dependence between youth and experience had created a very productive work culture at DRDL.

The first launch of the Missile Programme was conducted on 16 September 1985, when Trishul took off from the test range at Sriharikota (SHAR). It was a ballistic flight meant for testing the in-flight performance of the solid propellant rocket motor. Two C-Band radars and Kalidieo-theodolite (KTLs) were used to track the missile from the ground. The test was successful. The launcher, rocket motor and telemetry systems functioned as planned. The aerodynamic drag however was higher than the estimates predicted on the basis of wind tunnel testing. In terms of technology breakthrough or experience enrichment, this test was of little value but the real achievement of this test was to remind my DRDL friends that they could fly missiles without being driven by the brute demands of compliance or reverse engineering. In a swift stroke, the psyche of the DRDL scientists experienced a multi-dimensional expansion.

This was followed by the successful test flight of the Pilotless Target Aircraft (PTA). Our engineers had developed the rocket motor for the PTA designed by the Bangalore-based Aeronautical Development Establishment (ADE). The motor had been type- approved by DTD&P (Air). This was a small but significant step towards developing missile hardware that is not only functional but also acceptable to the user agencies. A private sector firm was engaged to produce a reliable, airworthy, high thrust-to-weight ratio rocket motor with technology input from DRDL. We were slowly graduating from single laboratory projects to multi-laboratory programmes to laboratory-industry exercises. The development of PTA symbolized a great confluence of four different organizations. I felt as if I was standing at a meeting point and looking at the roads coming from ADE, DTD&P (Air) and ISRO. The fourth road was the DRDL, a highway to national self-reliance in missile technology.

Taking our partnership with the academic institutions of the country a step further, Joint Advanced Technology Programmes were started at the Indian Institute of Science (IISc), and Jadavpur University. I have always had a deep regard for academic institutions and reverence for excellent academicians. I value the inputs that academicians can make to development. Formal requests had been placed with these institutions and arrangements arrived at under which expertise from their faculties would be extended to DRDL in pursuance of its projects.

Let me highlight a few contributions of academic institutions to the various missile systems. Prithvi had been designed as an inertially guided missile. To reach the target accurately, the trajectory parameters have to be loaded into its brain—an on-board computer. A team of young engineering graduates at Jadavpur University under the guidance of Prof. Ghoshal developed the required robust guidance algorithm. At the IISc, postgraduate students under the leadership of Prof. IG Sharma developed air defence software for multi-target acquisition by Akash. The re- entry vehicle system design methodology for Agni was developed by a young team at IIT Madras and DRDO scientists. Osmania University's Navigational Electronics Research and Training Unit had developed state-of-the-art signal processing algorithms for Nag. I have only given a few examples of collaborative endeavour. In fact, it would have been very difficult to achieve our advanced technological goals without the active partnership of our academic institutions.

Let us consider the example of the Agni payload breakthrough. Agni is a two-stage rocket system and employs re-entry technology developed in the country for the first time. It is boosted by a first-stage solid rocket motor derived from SLV-3 and further accelerated at the second stage with the liquid rocket engines of Prithvi. For the Agni, the payload gets delivered at hypersonic speeds, which calls for the design and development of a re-entry vehicle structure. The payload with guidance electronics is housed in the re-entry vehicle structure, which is meant to protect the payload by keeping the inside temperature within the limit of 40oC, when the outside skin temperature is greater than 2500oC. An inertial guidance system with an on-board computer guides the payload to the required target. For any re-entry missile system, three-dimensional preforms are core material for making the carbon-carbon nose tip that will remain strong even at such high temperatures. Four laboratories of DRDO and the CSIR achieved this in a short span of 18 months—something other countries could do only after a decade of research and development!

Another challenge involved in the Agni payload design was related to the tremendous speed with which it would re-enter the atmosphere. In fact, Agni would re-enter the atmosphere at twelve times the speed of sound (12 Mach, as we call it in science). At this tremendous speed, we had no experience of how to keep the vehicle under control. To carry out a test, we had no wind tunnel to generate that kind of speed. If we sought American help, we would have been seen as aspiring to something they considered their exclusive privilege. Even if they consented to co-operate, they would be certain to quote a price for their wind tunnel greater than our entire project budget. Now, the question was how to beat the system. Prof. SM Deshpande of the IISc found four young, bright scientists working in the field of fluid dynamics and, within six months, developed the software for Computational Fluid Dynamics for Hypersonic Regimes, which is one of its kind in the world.

Another achievement was the development of a missile trajectory simulation software, ANUKALPANA by Prof. IG Sharma of IISc to evaluate multi-target acquisition capabilities of an Akash-type weapon system. No country would have given us this kind of software, but we developed it indigenously.

In yet another example of creating a synergy of scientific talent, Prof. Bharati Bhatt of IIT Delhi, working with the Solid Physics Laboratory (SPL) and Central Electronics Limited (CEL), broke the monopoly of the western countries by developing ferrite phase shifters for use in the multi-function, multi-tasking 3-D Phased Army Radar for surveillence, tracking and guidance of Akash. Prof. Saraf of IIT, Kharagpur, working with BK Mukho-padhyay, my colleague at RCI, made a millimetric wave (MMW) antenna for the Nag Seeker Head in two years, a record even by international standards. The Central Electrical and Electronics Research Institute (CEERI), Pilani developed an Impatt Diode in consortium with the SPL and RCI to overcome technological foreign dependence in creating these components, which are the heart of any MMW device.

As work on the project spread horizontally, performance appraisal became more and more difficult. DRDO has an assessment-linked policy. Leading nearly 500 scientists, I had to finalize their performance appraisals in the form of Annual Confidential Reports (ACRs). These reports would be forwarded to an assessment board comprised of outside specialists for recommendations. Many people viewed this part of my job uncharitably. Missing a promotion was conveniently translated as a dislike I had towards them. Promotions of other colleagues were seen as subjective favours granted by me. Entrusted with the task of performance evaluation, I had to be a fair judge.

To truly understand a judge, you must understand the riddle of the scales; one side heaped high with hope, the other side holding apprehension. When the scales dip, bright optimism turns into silent panic.

When a person looks at himself, he is likely to misjudge what he finds. He sees only his intentions. Most people have good intentions and hence conclude that whatever they are doing is good. It is difficult for an individual to objectively judge his actions, which may be, and often are, contradictory to his good intentions. Most people come to work with the intention of doing it. Many of them do their work in a manner they find convenient and leave for home in the evening with a sense of satisfaction. They do not evaluate their performance, only their intentions. It is assumed that because an individual has worked with the intention of finishing his work in time, if delays occurred, they were due to reasons beyond his control. He had no intention of causing the delay. But if his action or inaction caused that delay, was it not intentional?

Looking back on my days as a young scientist, I am aware that one of the most constant and powerful urges I experienced was my desire to be more than what I was at that moment. I desired to feel more, learn more, express more. I desired to grow, improve, purify, expand. I never used any outside influence to advance my career. All I had was the inner urge to seek more within myself. The key to my motivation has always been to look at how far I had still to go rather than how far I had come. After all, what is life but a mixture of unsolved problems, ambiguous victories, and amorphous defeats?

The trouble is that we often merely analyse life instead of dealing with it. People dissect their failures for causes and effects, but seldom deal with them and gain experience to master them and thereby avoid their recurrence. This is my belief: that through difficulties and problems God gives us the opportunity to grow. So when your hopes and dreams and goals are dashed, search among the wreckage, you may find a golden opportunity hidden in the ruins.

To motivate people to enhance their performance and deal with depression is always a challenge for a leader. I have observed an analogy between a force field equilibrium and resistance to change in organizations. Let us imagine change to be a coiled spring in a field of opposing forces, such that some forces support change and others resist it. By increasing the supportive forces such as supervisory pressure, prospects of career growth and monetary benefits or decreasing the resisting forces such as group norms, social rewards, and work avoidance, the situation can be directed towards the desired result—but for a short time only, and that too only to a certain extent. After a while the resisting forces push back with greater force as they are compressed even more tightly. Therefore, a better approach would be to decrease the resisting force in such a manner that there is no concomittant increase in the supporting forces. In this way, less energy will be needed to bring about and maintain change.

The result of the forces I mentioned above, is motive. It is a force which is internal to the individual and forms the basis of his behaviour in the work environment. In my experience, most people possess a strong inner drive for growth, competence, and self- actualization. The problem, however, has been the lack of a work environment that stimulates and permits them to give full expression to this drive. Leaders can create a high productivity level by providing the appropriate organizational structure and job design, and by acknowledging and appreciating hard work.

I first attempted to build up such a supportive environment in 1983, while launching IGMDP. The projects were in the design phase at that time. The re-organization resulted in at least forty per cent to fifty per cent increase in the level of activity. Now that the multiple projects were entering into the development and flight-testing stage, the major and minor milestones reached gave the programme visibility and continuous commitment. With the absorption of a young team of scientists, the average age had been brought down from 42 to 33 years. I felt it was time for a second re-organization. But how should I go about it? I took stock of the motivational inventory available at that time—let me explain to you what I mean by this term. The motivational inventory of a leader is made up of three types of understanding: an understanding of the needs that people expect to satisfy in their jobs, an understanding of the effect that job design has on motivation, and an understanding of the power of positive reinforcement in influencing people's behaviour.

The 1983 re-organization was done with the objective of renewal: it was indeed a very complex exercise handled deftly by AV Ranga Rao and Col R Swaminathan. We created a team of newly-joined young scientists with just one experienced person and gave them the challenge of building the strap-down inertial guidance system, an on-board computer and a ram rocket in propulsion system. These exercises were being attempted for the first time in the country, and the technology involved was comparable with world-class systems. The guidance technology is centred around the gyro and accelerometer package, and electronics, to process the sensor output. The on-board computer carries the mission computations and flight sequencing. A ram rocket system breathes air to sustain its high velocity for long durations after it is put through a booster rocket. The young teams not only designed these systems but also developed them into operational equipment. Later Prithvi and then Agni used similar guidance systems, with excellent results. The effort of these young teams made the country self-reliant in the area of protected technologies. It was a good demonstration of the 'renewal factor'. Our intellectual capacity was renewed through contact with enthusiastic young minds and had achieved these outstanding results.

Now, besides the renewal of manpower, emphasis had to be laid on augmenting the strength of project groups. Often people seek to satisfy their social, egoistic, and self-actualization needs at their workplaces. A good leader must identify two different sets of environmental features. One, which satisfies a person's needs and the other, which creates dissatisfaction with his work. We have already observed that people look for those characteristics in their work that relate to the values and goals which they consider important as giving meaning to their lives. If a job meets the employees' need for achievement, recognition, responsibility, growth and advancement, they will work hard to achieve goals.

Once the work is satisfying, a person then looks at the environment and circumstances in the workplace. He observes the policies of the administration, qualities of his leader, security, status and working conditions. Then, he correlates these factors to the inter-personal relations he has with his peers and examines his personal life in the light of these factors. It is the agglomerate of all these aspects that decides the degree and quality of a person's effort and performance.

The matrix organization evolved in 1983 proved excellent in meeting all these requirements. So, while retaining this structure of the laboratory, we undertook a task-design exercise. The scientists working in technology directorates were made system managers to interact exclusively with one project. An external fabrication wing was formed under PK Biswas, a developmental fabrication technologist of long standing, to deal with the public sector undertakings (PSUs) and private sector firms associated with the development of the missile hardware. This reduced pressure on the in-house fabrication facilities and enabled them to concentrate on jobs which could not be undertaken outside, which in fact occupied all the three shifts.

Work on Prithvi was nearing completion when we entered 1988. For the first time in the country, clustered Liquid Propellant (LP) rocket engines with programmable total impulse were going to be used in a missile system to attain flexibility in payload range combination. Now, besides the scope and quality of the policy decisions Sundaram and I were providing to the Prithvi team, the project's success depended on creative ideas being converted into workable products and the quality and thoroughness of the team members' contribution. Saraswat with Y Gyaneshwar and P Venugopalan did a commendable job in this regard. They instilled in their team a sense of pride and achievement. The importance of these rocket engines was not restricted to the Prithvi project—it was a national achievement. Under their collective leadership, a large number of engineers and technicians understood and committed themselves to the team goals, as well as the specific goals which each one of them was committed to accomplish personally. Their entire team worked under a self-evident sort of direction. Working together with the Ordnance Factory, Kirkee, they also completely eliminated the import content in the propellant for these engines.

Leaving the vehicle development in the safe and efficient hands of Sundaram and Saraswat, I started looking at the mission's vulnerable areas. Meticulous planning had gone into the development of the launch release mechanism (LRM) for the smooth lift-off of the missile. The joint development of explosive bolts to hold the LRM prior to the launch by DRDL and Explosive Research and Development Laboratory (ERDL) was an excellent example of multi- work centre coordination.

While flying, drifting into spells of contemplation and looking down at the landscape below has always been my favourite preoccupation. It is so beautiful, so harmonious, so peaceful from a distance that I wonder where all those boundaries are which separate district from district, state from state, and country from country. Maybe such a sense of distance and detachment is required in dealing with all the activities of our life.

Since the Interim Test Range at Balasore was still at least a year away from completion, we had set up special facilities at SHAR for the launch of Prithvi. These included a launch pad, block house, control consoles and mobile telemetry stations. I had a happy reunion with my old friend MR Kurup who was the Director, SHAR Centre by then. Working with Kurup on the Prithvi launch campaign gave me great satisfaction. Kurup worked for Prithvi as a team member, ignoring the boundary lines that divide DRDO and ISRO, DRDL and SHAR. Kurup used to spend a lot of time with us at the launch pad. He complemented us with his experience in range testing and range safety and worked with great enthusiasm in propellant filling, making the maiden Prithvi launch campaign a memorable experience.

Prithvi was launched at 11:23 hrs on 25 February 1988. It was an epoch-making event in the history of rocketry in the country. Prithvi was not merely a surface-to-surface missile with a capability of delivering a 1000 kg conventional warhead to a distance of 150 km with an accuracy of 50 meter CEP; it was in fact the basic module for all future guided missiles in the country. It already had the provision for modification from a long-range surface to an air missile system, and could also be deployed on a ship.

The accuracy of a missile is expressed in terms of its Circular Error Probable (CEP). This measures the radius of a circle within which 50 per cent of the missiles fired will impact. In other words, if a missile has a CEP of 1 km (such as the Iraqi Scud missiles fired in the Gulf War), this means that half of them should impact within 1 km of their target. A missile with a conventional high-explosive warhead and a CEP of 1 km would not normally be expected to destroy or disable fixed military targets such as a Command and Control Facility or an Air Base. It would however be effective against an undefined target such as a city.

The German V-2 missiles fired at London between September 1944 and March 1945 had a conventional high-explosive warhead and a very large CEP of some 17 km. Yet the 500 V-2s which hit London succeeded in causing more than 21,000 casualties and destroying about 200,000 homes.

When the West were crying themselves hoarse over the NPT, we stressed upon building competence in core guidance and control technologies to achieve a CEP as precise as 50 m. With the success of the Prithvi trials, the cold reality of a possible strategic strike even without a nuclear warhead had silenced the critics to whispers about a possible technology-conspiracy theory.

The launch of Prithvi sent shock waves across the unfriendly neighbouring countries. The response of the Western bloc was initially one of shock and then of anger. A seven-nation technology embargo was clamped, making it impossible for India to buy anything even remotely connected with the development of guided missiles. The emergence of India as a self-reliant country in the field of guided missiles upset all the developed nations of the world.

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Torchbearers

Indian core competence in rocketry has been firmly established again, beyond any doubt. The robust civilian space industry and viable missile-based defences has brought India into the select club of nations that call themselves superpowers. Always encouraged to follow Buddha's or Gandhi's teachings, how and why did India become a missile power is a question that needs to be answered for future generations.

Two centuries of subjugation, oppression and denial have failed to kill the creativity and capability of the Indian people. Within just a decade of gaining independence and achieving sovereignty, Indian Space and Atomic Energy Programmes were launched with a perfect orientation towards peaceful applications. There were neither funds for investing in missile development nor any established requirement from the Armed Forces. The bitter experiences of 1962 forced us to take the basic first steps towards missile development.

Would a Prithvi suffice? Would the indigenous development of four or five missile systems make us sufficiently strong? Or would having nuclear weapons make us stronger? Missiles and atomic weapons are merely parts of a greater whole. As I saw it, the development of Prithvi represented the self-reliance of our country in the field of advanced technology. High technology is synonymous with huge amounts of money and massive infrastructure. Neither of these was available, unfortunately, in adequate measure. So what could we do? Perhaps the Agni missile being developed as a technology demonstrator project, pooling all the resources available in the country, could provide an answer?

I was very sure, even when we discussed REX in ISRO about a decade ago, that Indian scientists and technologists working together had the capability to achieve this technological breakthrough. India can most certainly achieve state-of-the-art technology through a combined effort of the scientific laboratories and the academic institutions. If one can liberate Indian industry from the self-created image of being mere fabricating factories, they can implement indigenously developed technology and attain excellent results. To do this, we adopted a three-fold strategy— multi-institutional participation, the consortium approach, and the empowering technology. These were the stones rubbed together to create Agni.

The Agni team was comprised of more than 500 scientists. Many organizations were networked to undertake this huge effort of launching Agni. The Agni mission had two basic orientations— work and workers. Each member was dependent on the others in his team to accomplish his target. Contradiction and confusion are the two things most likely to occur in such situations. Different leaders accommodate concern for workers while getting work done, in their own personal ways. Some shed all concern for workers in order to get results. They use people merely as instruments to reach goals. Some give less importance to the work, and make an effort to gain the warmth and approval of people working with them. But what this team achieved was the highest possible integration in terms of both the quality of work and human relationships.

Involvement, participation and commitment were the key words to functioning. Each of the team members appeared to be performing by choice. The launching of Agni was the common stake not only for our scientists, but for their families too. VR Nagaraj was the leader of the electrical integration team. Dedicated technologist that he is, Nagaraj would forget basic requirements like food and sleep while on the integration gig. His brother-in-law passed away while he was at ITR. His family kept this information from Nagaraj so that there would be no interruption in his work towards the launching of Agni.

The Agni launch had been scheduled for 20 April 1989. This was going to be an unprecedented exercise. Unlike space launch vehicles, a missile launch involves wide-ranging safety hazards. Two radars, three telemetry stations, one telecommand station and four electro-optical tracking instruments to monitor the missile trajectory had been deployed. In addition, the telemetry station at Car Nicobar (ISTRAC) and the SHAR radars were also commissioned to track the vehicle. Dynamic surveillance was employed to cover the electrical power that flows from the missile batteries within the vehicle and to control system pressures. Should any deviation be noticed either in voltage or in pressure, the specially designed automatic checkout system would signal “Hold”. The flight operations would then be sequenced only if the defect was rectified. The countdown for the launch started at T-36 hours. The countdown from T-7.5 minutes was to be computer controlled.

All activities preparatory to the launch went according to schedule. We had decided to move the people living in nearby villages to safety at the time of the launch. This attracted media attention, and led to much controversy. By the time 20 April 1989 arrived, the whole nation was watching us. Foreign pressure was exerted through diplomatic channels to abort the flight trial, but the Indian Government stood behind us like a rock and staved off any distraction to our work. We were at T-14 seconds when the computer signalled “Hold”, indicating that one of the instruments was functioning erratically. This was immediately rectified. Meanwhile, the down-range station asked for a “Hold”. In another few seconds, multiple Holds were necessitated, resulting in irreversible internal power consumption. We had to abort the launch. The missile had to be opened up to replace the on-board power supplies. A weeping Nagaraj, by now informed about the tragedy in his family, met me and promised that he would be back within three days. The profiles of these courageous people will never be written about in any history book, but it is such silent people on whose hard work generations thrive and nations progress. Sending Nagaraj off, I met my team members who were in a state of shock and sorrow. I shared my SLV-3 experience with them. “I lost my launch vehicle in the sea but recovered successfully. Your missile is in front of you. In fact you have lost nothing but a few weeks of rework.” This shook them out of their immobility and the entire team went back to retrieve the subsystems and re-charge them.

The press was up in arms, and fielded various interpretations of the postponement of the flight to suit the fancies of their readership. Cartoonist Sudhir Dar sketched a shopkeeper returning a product to the salesman saying that like Agni it would not take off. Another cartoonist showed one Agni scientist explaining that the launch was postponed because the press button did not make contact. The Hindustan Times showed a leader consoling press reporters, “There’s no need for any alarm ... it’s a purely peaceful, non-violent missile”.

After a detailed analysis conducted virtually around the clock for the next ten days, our scientists had the missile ready for launch on 1 May 1989. But, again, during the automatic computer checkout period at T-10 seconds, a Hold signal was indicated. A closer inspection showed that one of the control components, S1-TVC was not working according to the mission requirements. The launch had to be postponed yet again. Now, such things are very common in rocketry and quite often happen in other countries too. But the expectant nation was in no mood to appreciate our difficulties. The Hindu carried a cartoon by Keshav showing a villager counting some currency notes and commenting to another, “Yes, it’s the compensation for moving away from my hut near the test site—a few more postponements and I can build a house of my own...”. Another cartoonist designated Agni as “ IDBM— Intermittently Delayed Ballistic Missile.” Amul’s cartoon suggested that what Agni needed to do was use their butter as fuel!

I took some time off, leaving my team at ITR to talk to the DRDL-RCI community. The entire DRDL-RCI community assembled after working hours on 8 May 1989. I addressed the gathering of more than 2,000 persons, “Very rarely is a laboratory or an R&D establishment given an opportunity to be the first in the country to develop a system such as Agni. A great opportunity has been given to us. Naturally major opportunities are accompanied by equally major challenges. We should not give up and we should not allow the problem to defeat us. The country doesn’t deserve anything less than success from us. Let us aim for success”. I had almost completed my address, when I found myself telling my people, “I promise you, we will be back after successfully launching Agni before the end of this month.”

Detailed analysis of the component failure during the second attempt led to the refurbishment of the control system. This task was entrusted to a DRDO-ISRO team. The team carried out the rectification of the first stage control system at the Liquid Propellant System Complex (LPSC) of ISRO and completed the task in record time with tremendous concentration and will-power. It was nothing short of amazing how hundreds of scientists and staff worked continuously and completed the system readiness with acceptance tests in just 10 days. The aircraft took off from Trivandrum with the rectified control systems and landed close to ITR on the eleventh day. But now it was the turn of hostile weather conditions to impede us. A cyclone threat was looming large. All the work centres were connected through satellite communication and HF links. Meteorological data started flowing in at ten-minute intervals.

Finally, the launch was scheduled for 22 May 1989. The previous night, Dr Arunachalam, Gen KN Singh and I were walking together with the Defence Minister KC Pant, who had come to ITR to witness the launch. It was a full-moon night, it was high tide and the waves crashed and roared, as if singing of His glory and power. Would we succeed with the Agni launch tomorrow? This question was foremost in all our minds, but none of us was willing to break the spell cast by the beautiful moonlit night. Breaking a long silence, the Defence Minister finally asked me, “Kalam! what would you like me to do to celebrate the Agni success tomorrow?” It was a simple question, to which I could not think of an answer immediately. What did I want? What was it that I did not have? What could make me happier? And then I found the answer. “We need 100,000 saplings to plant at RCI,” I said. His face lit up with a friendly glow. “You are buying the blessings of Mother Earth for Agni,” Defence Minister KC Pant quipped. “We will succeed tomorrow”, he predicted.

The next day Agni took off at 0710 hrs. It was a perfect launch. The missile followed a textbook trajectory. All flight parameters were met. It was like waking up to a beautiful morning from a nightmarish sleep. We had reached the launch pad after five years of continuous work at multiple work centres. We had lived through the ordeal of a series of snags in the last five weeks. We had survived pressure from everywhere to stop the whole thing. But we did it at last! It was one of the greatest moments of my life. A mere 600 seconds of elegant flight washed off our entire fatigue in an instant. What a wonderful culmination of our years of labour. I wrote in my diary that night:

Do not look at Agni
as an entity directed upward
to deter the ominous
or exhibit your might.
It is fire
in the heart of an Indian.
Do not even give it
the form of a missile
as it clings to the
burning pride of this nation
and thus is bright.

Prime Minister Rajiv Gandhi called the Agni launch “a major achievement in our continuing efforts to safeguard our independence and security by self-reliant means. The technology demonstration through Agni is a reflection of our commitment to the indigenous development of advanced technologies for the nation’s defence.” “The country is proud of your efforts,” he told me. President Venkataraman saw in the Agni success the fulfilment of his dream. He cabled from Simla, “It is a tribute to your dedication, hard work, and talent.”

A great deal of misinformation and disinformation had been spread by vested interests about this technology mission. Agni had never been intended only as a nuclear weapon system. What it did was to afford us the option of developing the ability to deliver non-nuclear weapons with high precision at long ranges. That it provided us with a viable non-nuclear option was of the greatest relevance to contemporary strategic doctrines.

Great ire was raised by the test firing of Agni, according to a well-known American defence journal, especially in the United States where Congressmen threatened to put a stop to all dual-use and missile-related technologies, along with all multinational aid.

Gary Milhollin, a so-called specialist in missiles and warhead technologies, had made a claim in The Wall Street Journal that India had made Agni with the help of West Germany. I had a hearty laugh reading that the German Aerospace Research Establishment (DLR) had developed Agni’s guidance system, the first-stage rocket, and a composite nose cone, and that the aerodynamic model of Agni was tested in the DLR wind tunnel. An immediate denial came from the DLR, who in turn speculated that France had supplied the Agni guidance electronics. American Senator Jeff Bingaman even went to the extent of suggesting that I picked up everything needed for Agni during my four-month stay at Wallop’s Island in 1962. The fact that I was in Wallop’s Island more than 25 years ago and at that time the technology used in Agni did not exist even in the United States was not mentioned.

In today’s world, technological backwardness leads to subjugation. Can we allow our freedom to be compromised on this account? It is our bounden duty to guarantee the security and integrity of our nation against this threat. Should we not uphold the mandate bequeathed to us by our forefathers who fought for the liberation of our country from imperialism? Only when we are technologically self-reliant will we able to fulfill their dream.

Till the Agni launch, the Indian Armed Forces had been structured for a strictly defensive role to safeguard our nation, to shield our democratic processes from the turbulence in the countries around us and to raise the cost of any external intervention to an unacceptable level for countries which may entertain such notions. With Agni, India had reached the stage where she had the option of preventing wars involving her.

Agni marked the completion of five years of IGMDP. Now that it had demonstrated our competence in the crucial area of re-entry technology and with tactical missiles like Prithvi and Trishul already test-fired, the launches of Nag and Akash would take us into areas of competence where there is little or no international competition. These two missile systems contained within themselves the stuff of major technological breakthroughs. There was a need to focus our efforts more intensively on them.

In September 1989, I was invited by the Maharashtra Academy of Sciences in Bombay to deliver the Jawaharlal Nehru Memorial Lecture. I used this opportunity to share with the budding scientists my plans of making an indigenous Air-to-Air missile, Astra. It would dovetail with the development of the Indian Light Combat Aircraft (LCA). I told them that our work in Imaging Infra Red (IIR) and Millimetric Wave (MMW) radar technology for the Nag missile system had placed us in the vanguard of international R&D efforts in missile technology. I also drew their attention to the crucial role that carbon-carbon and other advanced composite materials play in mastering the re-entry technology. Agni was the conclusion of a technological effort that was given its start by Prime Minister Indira Gandhi when the country decided to break free from the paralysing fetters of technological backwardness and slough off the dead skin of subordination to industrialized nations.

The second flight of Prithvi at the end of September 1988 was again a great success. Prithvi has proved to be the best surface-to-surface missile in the world today. It can carry 1000 kg of warhead to a distance of 250 km and deliver it within a radius of 50 metres. Through computer controlled operations, numerous warhead weight and delivery distance combinations can be achieved in a very short time and in battlefield conditions. It is a hundred per cent indigenous in all respects—design, operations, deployment. It can be produced in large numbers as the production facilities at BDL were concurrently developed during the development phase itself. The Army was quick to recognize the potential of this commendable effort and approached the CCPA for placing orders for Prithvi and Trishul missile systems, something that had never happened before.

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