Defence Science Journal, VOL. 52, NO. 1, January 2002, pp. 11-20


# Integrated Process for Smooth Transition from Development to Production of Weapon Systems

V.S.C. Bose and V. Krishna
*Defence Research & Development Laboratory, Hyderabad–500 058*

**ABSTRACT**

Production of weapon systems has proven to be as difficult as their development. The transition from development to production encompasses innumerable efforts to take a weapon system from laboratory into full-scale production. These efforts may span the development and production phases and constitute a major determinant of a weapon system's production costs. Besides, Indian manufacturers/production units, who seek know-how, generally go to foreign manufacturers and obtain complete production know-how. Obviously, they expect same kind of technological support, which are the preserves of the manufacturers'. An attempt has been made for the first time by Defence Research & Development Laboratory (DRDL), Hyderabad for a technology transfer of highly sophisticated missiles to production agency. Experiences show that the technology receiver (i.e. production agency) should have a willingness to receive the technology and the technology donor should understand the culture of technology receiver and recode/restructure the technological information to fit into the technology receiver's domain. Production planning and preparations were conducted throughout the development phase to identify production requirements and to resolve the difficulties before production begins to achieve quality products. A unique technology transfer mechanism has been evolved and implemented successfully for one of the weapon systems developed by DRDL, Hyderabad. Production agencies have demonstrated their capability to produce subsystems of a weapon system of desired quality within the time schedule and cost by the time the weapon system performance was demonstrated to the users. Also, the deliveries of systems of development hardware continued into the production phase and production deliveries began with no line interruption.

**Keywords**: Technology transfer, weapon systems, production agencies, weapon system development, full-scale production, missiles

## 1. INTRODUCTION

No model or mechanism, designed for successful technology transfer has been proposed as on today. Conventional techniques like technology transfer by passive mode, active mode, semi-active mode and technology diffusion are not applicable for transfer of advanced technology and highly sophisticated weapon systems. The authors are of the opinion that, 'technology transfer for weapon system should mean the transfer of entire content of knowledge and transfer of hardware and know-how to manage resources, infrastructure, plan product, maintain balance between technical concerns and production concerns and finally productionise and successfully impart training in operation and deployment of weapon system'.

Technology transfer is besieged with many hurdles which may include lack of efficient path from raw material proucurement and manufacture to deployment. If these hurdles are not addressed, a number of solutions will never reach deployment stage and will result in an ineffective path of technology

Received 05 November 2001

transfer and form poor operational performances. Technology transfer activities should commence right from the inception of the project. Studies by Kunihiko[1] suggested a four-stage technology transfer process whereas Junzheng and Jaideep[2] suggested a five-stage technology transfer process from manufacturer-to-manufacturer (public sector to private sector) which includes many participants as shown below:

(a) Provision of technology: Technology providers can be universities; national laboratories (industries, agriculture, and medical research laboratories, space research laboratories, atomic energy laboratories, defence research laboratories, etc.); research divisions in public sector and private sector units, foreign companies (joint venture) and consulting firms.

(b) Kinds of technology: Technologies provided by universities and laboratories are mostly hardware- oriented, short-term-oriented incremental technologies and long-term-oriented innovative technologies. Software technologies (information technologies) are provided by consulting firms.

(c) Search for technology: Interested companies conduct search for needed technologies. Consulting firms are best referred to for searching the technologies, because they have better access to information. Besides, contract research and expert services can also give good results for searching new technologies.

(d) Negotiations for conditions between provider and buyer: Technology transfer mechanism could be either through contract research, research projects, generating on user demand (based on user reqirement) joint ventures and patents, and licenses.

(e) Acquisition of technology: Acquisition of technology mainly depends upon the role of the provider and the buyer. Technology can be acquired through memorandum of understanding (MOU) in the form of absorption technology, adaptation technology and adoption technology. This is either from Govt laboratories or from private sectors. Once the aforesaid stages (a, b, c and d) are complete, technology transfer will take place from the provider to the buyer. Usually, the acquisition process takes long time because of many uncertainty factors. Also, it depends upon the capability of the provider of technology and adoption and absorption of the transferred technology by the buyer.

(f) Service and support: Provider of the technology should help the buyer to understand and apply the technology, bearing in mind the protection of intellectual property rights associated with the technology transfer. The product produced should be maintainable throughout its life cycle.

Experiences have shown that production of weapon systems has proven to be as difficult as their development. The transition from development to production encompasses innumerable efforts to take weapon systems from laboratories into full-scale production. These efforts span the development and production phases and constitute a major determinant of a weapon system's production costs. Technology transfer is a person-oriented phenomenon, and therefore culture forms an integral part of technology transfer and its success depend upon a close relationship between the parties involved to overcome transfer barriers.

Conventionally, weapon system acquisition cycle constitutes a concept exploration, demonstration and validation of design, full-scale development and production, and deployment. Each phase precedes a management review and the experiences show that the last phase of production continued several years to achieve the desired rate of production as well as filling the inventory. This is mainly because of the following technical problems:

- The pressure to achieve technical performance dominates the development phase

- Design employing advanced technology encounters more problems--needs management attention

- Delays in setting up production facilities and equipment
- Lack of strong integrator/multi-function team in multidisciplinary and multi-production agencies environment
- Lack of strong design and development base in production units to absorb and adopt new technologies
- Producibility problems
- Redesign which may require changes in tooling, test equipment and/or manufacturing processes and may include retrofit
- Inadequate recoding and restructuring of technical information for fitting into the production environment
- Ambiguity in defining technical problems to properly assess and arrive at a quality solution
- Differences in skills between technicians of laboratories and production units
- Availability of special tooling and test equipment to achieve high degree of accuracy required by component/system part specifications
- Dependence on foreign sources for components/ items
- Increase in lead times needed to procure critical parts and materials
- Low yields due to a high percentage of parts that must be scrapped or reworked
- Preparation of a production document.

These problems manifest themselves in parts shortage and in extra labour and machine time to rework parts to meet tolerances.

## 2. TECHNOLOGY TRANSFER FOR WEAPON SYSTEMS

Indian manufacturers who seek know-how, generally go to foreign manufacturers and obtain complete production know-how (licensed production), including equipment, production drawings and documents, tooling, etc. Obviously, Indian laboratories are expected to provide the kind of technological support, which the preserves of manufacturers' abroad.

An attempt has been made to transfer technologies of highly sophisticated missiles developed under integrated guided missiles development programme (IGMDP) to both public sector undertakings (PSUs) and private sector manufacturers/fabricators. In doing so, concurrency concept has been adopted to minimise the time and also to cater for the production problems by manufacturing developmental units by production agencies and has been implemented by introducing various production centres to the missile development tasks during the early stages of development also. The concurrency concept has been adopted for smooth technology transfer, as it addresses issues simultaneously during development and production.

Conventionally, technology transfer is assisted through a technology transfer agent/champion. Unique nature of technology of missiles forbids the intervention/interference of a third party. Such technologies should be transferred by the developing agencies themselves or create mechanisms to do so. In sophisticated technologies, acquisition of technology in terms of drawings, specifications, material, test equipment and procedures, tooling, manufacturing process and product as a whole may take three to five years, besides political and economical overtones.

There are several steps to be taken before technology dseveloped by a laboratory can be transformed into production. There may be several gaps in the production process which neither the laboratory nor the manufacturing agencies are able to fill. Hence, concurrent mode of technology transfer has been adopted to fill the gaps for smooth transition from development to full-scale production. Technology receivers/prime production agencies have to be closely associated with Defence laboratories in acquiring technologies. The technologies of this class (IGMDP) are normally based on new innovations/ideas and are radically different from the conventional technologies, normally available to the production concerns in terms of software. No viable methods are available for horizontal sliding of technology from research and development centres to production agencies except a concurrent mode for meeting some of the significant and essential requirements for early deployment of a developed weapon system.

### 2.1 Strategy for Technology Transfer

While carrying out technology transfer, the strategy followed is:

- Technology transfer connotes the transfer of total content of knowledge and hardware and know-how of resource management, infrastructure, plan product, maintain balance between technical concerns and production concerns and finally productionise and successfully impart training in operation, maintenance and deployment of weapon systems.

- For an effective transfer of technical information, one must make use of human ability to recode and restructure information so that it fits into new contents and situations. Consequently, the best way to transfer technical information is to move a human carrier.

- The involvement of technology receivers/ production agencies in technology transfer ranges from superficial input early in the development process (where minor alterations to the technology were considered), to actual development of partnership between the technology source and the receiver for absorption of innovations from the beginning.

- It can be inefficient or even risky from the beginning of a technology project for technology developers and implementation managers, if they cannot understand what kind of transfer situation they are managing. Similarly, manufacturers of new technology need to understand through which modes they are receiving, in order to allocate resources appropriately, as well as to position enough number of production personnel.

- Technology transfer was considered as critical in development phase and was treated as technical discipline problem and received balanced treatment with other technical disciplines.

- A close and effective communication and strong commitment to success are necessary on both sides, if technology is to be developed and transitioned successfully.

- The production engineering and planning was done during full-scale development and the production engineers properly planned and prepared for production.

- Production risks were identified as early as possible, beginning with the first stage of development and these risks were minimised before production commenced.

- Voids in production technologies were identified and addressed.

- Production agencies during development phase demonstrated their capabilities to produce the item within the estimated cost and time schedule.

- During development, several factors, in particular, the design instabilities arising from a highly technical design, changes in technical requirements, export controls (like Missile Treaty Control Regime) of missile-related items in countries abroad, increasing lead times needed to procure critical items and materials and insufficient resources can hamper production preparation and these were taken care of.

- Production readiness reviews were conducted during the entire span, from development to full-scale production, for proper management of technology transfer and productionisation.

- For the transfer of technology to take place, the receiving organisation was so chosen that it was capable of and interested in receiving the information. Both donor and receiver overlapped in self-confidence to ask questions and really probe the information being transmitted. Finally, recipient organisation (production agencies) were able to distinguish between the changes in processes or techniques and changes that were inevitable and permissible and those that vitiate the new technology.

- Besides, the research and development (R&D) personnel understood the manufacturing environment, and also recognised the enormous and overriding commitment that manufacturing personnel make for achieving uninterrupted output.

- The manufacturing agencies were adaptive in incorporating new technology. The shop environment possess severe constraints in adapting new manufacturing techniques and new product technologies. New manufacturing techniques require learning new skills, create anxiety and resentment and change status relationships that alter communication patterns. Manufacturing personnel have a very limited experimental tradition. It can be possible that manufacturing personnel, because of professional jealousy or scientific jealousy, block the technology transfer. Diplomatic approach is needed in overcoming such barriers.

- The manufacturing agencies were assisted in taking action for early setting up of the needed production facilities, test equipment and tooling and to overcome production problems during development phase.

- The manufacturers generally do not have adequate technical proficiency to be able to talk to R&D personnel, as they are not familiar with production environment. This makes it difficult for R&D personnel to identify and characterise the problems of manufacturers. Besides, technologists do not understand management and that managers do not understand the technology they manage. Lack of common language and techniques for identifying technical problems require creation of a common platform for solving such problems.

- The manufacturing personnel are not familiar with the tradition of professional interaction that is common in R&D. Manufacturing personnel believe that new technology must be carefully tailored to the requirements of local environment and understanding.

Therefore, technology transfer connotes interfaces and barriers and overcoming such barriers needs involvement of people with a manufacturing background in technology development.

## 2.2 Methodology

Production of large-size weapon systems is as difficult as their development. Technology transfer activities begin with identifying component technologies and setting up facilities/augmenting facilities. Contractors for development/fabrication shall be identified based on the past performance, production management capability, quality history and the potential to execute the production programme.

Bearing above in mind, a four-stage technology transfer process was designed and implemented to transfer the missile technology from a design agency to the production agencies. Technology transfer without human carrier is hollow. Technical concerned of technology provider designed jointly with production concerned of a fabricating company, fabricated or constructed prototype according to the design specifications and offered to the users for inspection (qualification and acceptance) and the product was evaluated by all the four parties (designer, manufacturer, project team and user). In this way, close communication links between adjacent activities are institutionalised. A consortium of PSUs was adopted. Inspection and maintenance agencies were also associated from the development stage. Clear definition of technology transfer was arrived at.

The document for technology transfer was generated providing appropriate standards, formats, procedures and processes, and guidelines in the first stage, nurtured during second stages, implemented the procedures laid down in the document in the third stage and in the final stage, refined the technology

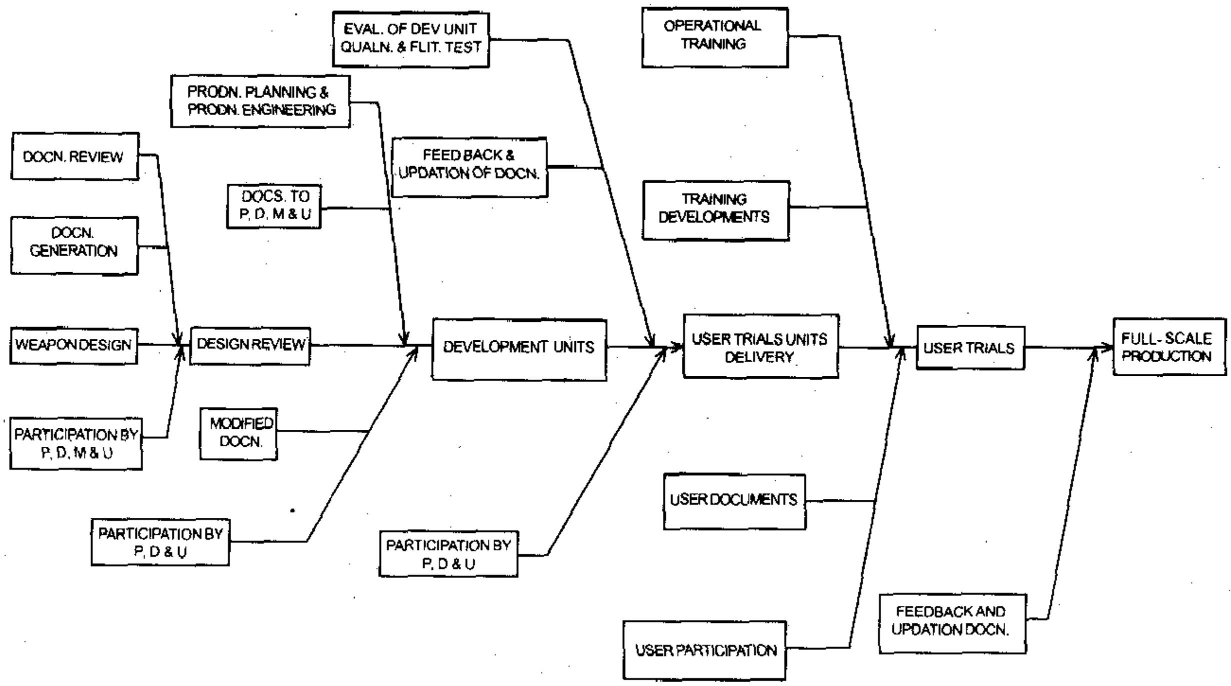


**Figure 1. Technology transfer process**

by standardising and optimising at regular intervals and also at project milestones. All details during design, development, manufacture and testing were captured and documented during the development cycle to reduce the problems in technology transfer. Fish bone diagram of a technology transfer process is shown in Fig. 1. In concurrent modes of technology transfer, it is essential to have documents and drawings controlled. Procedures were laid down to ensure that the task performers are aware of the existence and the availability of documents governing their tasks. In exercising the transfer of entire technical information to the extent possible in a codified form, design engineering drawings were standardised to production standards.

While imparting the technology in concurrent mode, it is necessary to consider requests/suggestions made by production and inspection agencies on each subsystem for ease of manufacture, adequacy of tests for achieving quality product and conformity to the specifications. Change-control methodology was adopted to bring out various factors into the systematic fold of technology transfer. Two review mechanisms were adopted, where a component deviated from its intended specifications during manufacture and post-production deviations during testing of components for modifying components. These review mechanisms are controlled by various committees like Waiver Board, Standing Design Review Committee and Document Review Committee to control the configuration of weapon systems.

All the stages of technology transfer process were reviewed by preliminary design review committee and critical design review committee. Based on the input received from the designer, types of documents were identified depending on the complexity of technology of subsystems. These documents were generated, reviewed by production agencies and inspection agencies. Development units were fabricated by the production agencies based on the documented technical information and participation of design engineers. These units were tested dynamically (test-fired) and had undergone qualification tests. The results of these tests were evaluated by a competent team and the documentation was updated.

## 3. RESULTS & DISCUSSION

Using this mode of technology transfer, production risks were identified as early as beginning of the first stage of development, and these risks were minimised. In a concurrent mode of technology transfer, the advantage is specially in addressing the issues (technical and production problems) during development, which lead to smooth technology transfer from development to production.Production Engineering and planning were done throughout full-scale development. Voids in production were identified and addressed. Before proceeding into full-scale production, contractors had demonstrated their capabilities to produce systems/subsystems within the estimated cost and time schedule. Had the designs been frozen, there would have been little room to introduce changes in the interest of producibility. Weapon systems have to be so designed to incorporate improved/advanced (proven) technologies during development. All previously tried production processes were adopted which could produce components meeting specifications. Production engineers were prepared to meet the required rate of production with the experience gained during developmental periods. Tolerances, found rigid and not producible, were addressed during the development phase. Unnecessary processes and quality tests were eliminated. The sequence of production preparations leading to production decision is shown in the bar chart Fig. 2.

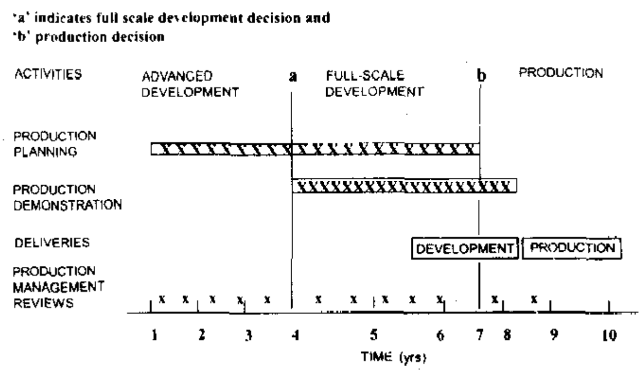


**Figure 2. Bar chart showing decisions regarding development and production wrt time.**

Production readiness was reviewed by production management committee and carried out throughout the project. Readiness review had became a methodical examination of this programme to verify whether the production design, planning and associated preparations for a system have progressed to the point where a production commitment can be made without incurring unacceptable risks. In this programme, a nodal production agency was identified and made responsible for realisation of subsystems/ systems and integration of the missiles.

## 4. SUMMARY

Technology transfer of the laboratory-developed model to productionisation is quite a complex operation, but it is highly vulnerable when over-simplified. Smooth transition from development to production (Fig. 3) of missiles in the IGMDP is due to the following:

Technical information was communicated quickly and widely onto the floor level with minimum hierarchy and job classification. Face-to-face communication and constant interaction among technical/production/inspection personnel and users were given paramount importance. A large-size weapon system development and production involves three or more different organisations. As such, a proper mechanism for conflict resolution was worked out. Protection of information was abandoned and replaced by openness. Cooperation was filtered down to managerial and operational personnel, which has resulted in smooth transition of technology from development to production. Real-time networking of related laboratories of the Defence Research and Development Organisation (DRDO) and PSUs has been planned for improving the technology transfer process.

## 5. CONCLUSIONS

The following are some of the suggestions for smooth technology transfer from an R&D agency to production agency for hi-technologies/ weapon systems and could be made as production policy for weapon systems:

(a) Adoption of concurrent engineering for reducing cost and time

(b) Production preparedness should be treated as technical discipline problem that must receive balanced treatment in development with other technical discipline and should be treated as critical elements of production phase, such as performance and supportability.

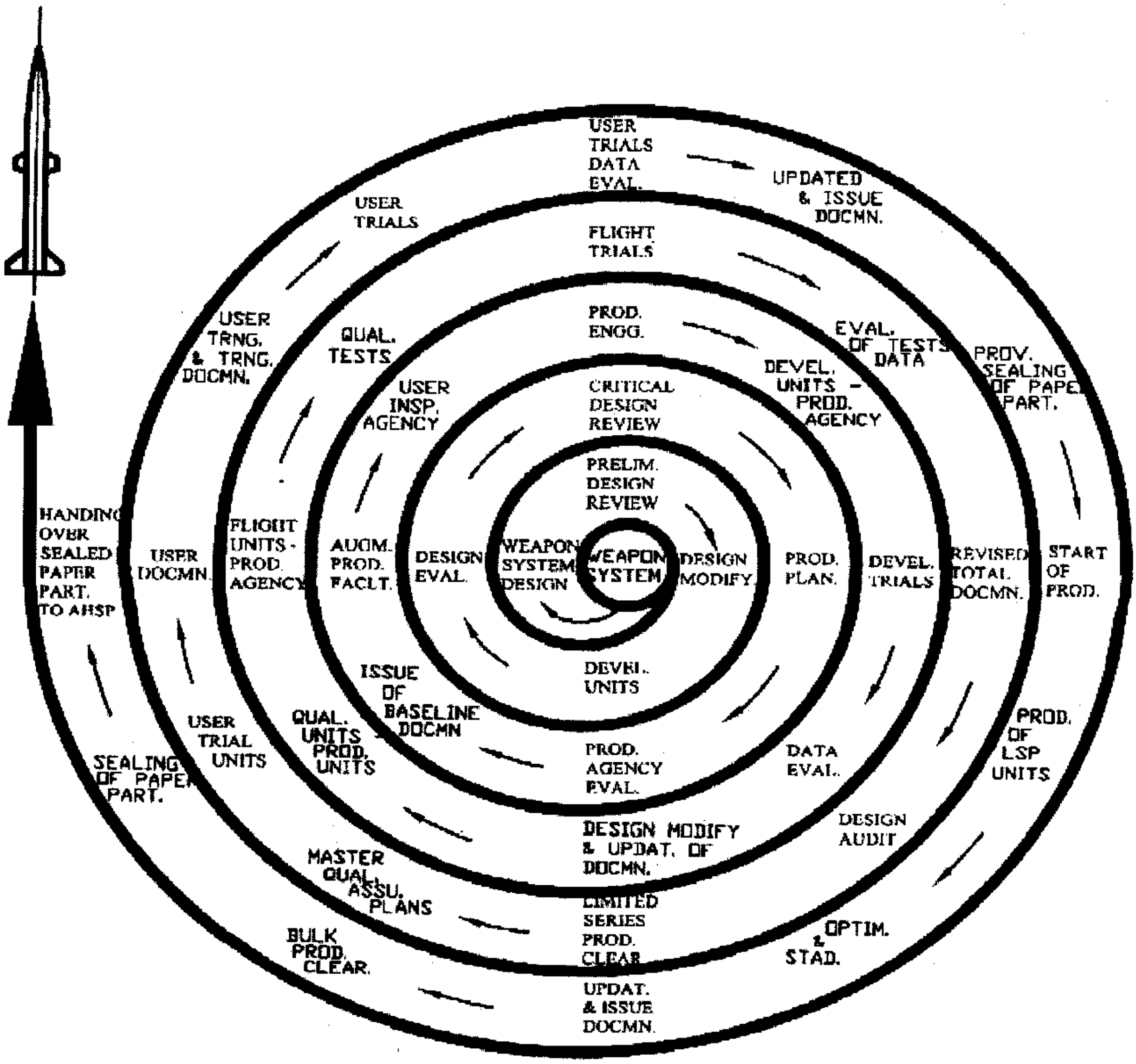


**Figure 3. Transition from development to production**

| | | | | | |
|---|---|---|---|---|---|
| AUGM | = | AUGUMENT | MODIFY | = | MODIFICATION |
| ASSU | = | ASSURANCE | OPTIM | = | OPTIMISATION |
| BOMS | = | BILL OF MATERIALS | PART | = | PARTICULARS |
| CLEAR | = | CLEARANCE | PLAN | = | PLANNING |
| DEFIN | = | DEFINITION | PRELIM | = | PRELIMINARY |
| DEVEL | = | DEVELOPMENT | PROV | = | PROVISIONAL |
| DOCMN | = | DOCUMENTATION | PROD | = | PRODUCTION |
| ENGG | = | ENGINEERING | QUAL | = | QUALIFICATION |
| EVAL | = | EVALUATION | STAND | = | STANDARDISATION |
| FACLT | = | FACILITIES | TRNG | = | TRAINING |
| INSP | = | INSPECTION | UPDAT | = | UPDATION |

(c) Emphasis should be placed on application of fundamental engineering principles and relevant technical disciplines during development and production. Assessment of production risks should be made throughout the acquisition process. These assessments should be formalised through production readiness reviews. Risks should be reduced to acceptable levels.

(d) A manufacturing strategy should be developed as a part of the programme acquisition strategy. Manufacturing voids, deficiencies and dependencies on critical foreign source materials should be addressed concurrently with concept demonstration and validation through the use of manufacturing technology projects or other means. The reducibility of each system design concept should be evaluated at the full-scale development decision point to determine if the proposed system can be manufactured in compliance with the production cost and industrial base goals and thresholds.

(e) Single production centre (prime production agency) should be responsible for integration of weapon system components with adequate trained staff.

(f) Contractor's past performance (to the extent that it has a bearing on the concept involved) production management capability, quality history and the potential to execute the production programme should be included in the contractual solicitations and evaluated thereafter in the source selection.

(g) A comprehensive producibility engineering and planning programme is a requisite for entering full-scale development. Engineering and planning programmes should be conducted throughout full-scale development and shall contain specific tasks, measurable goals and system of contractor accountability.

(h) A quality programme should be conducted throughout acquisition and deployment. Production preparedness planning should be integrated effectively with production management and planning.

(i) The monitoring committees should conduct reviews throughout the process, from the development to the production phases.

(j) The manufacturing agency must have at its disposal an R&D team working not only on improvement of current catalogue of products but also on new products and new technological absorptions.

(k) The manufacturers should build-up enough expertise to provide valuable feedback on the technology transferred to the designers.

## ACKNOWLEDGEMENTS

The authors wish to express their gratitude to Shri Prahlada, Director, DRDL for his valuable suggestions, guidance and permission to publish this work. The authors also express their gratitude to Dr V.K. Saraswat, Programme Director for overall support and encouragement. The support provided by their colleagues is also gratefully acknowledged.

## 6. REFERENCES

1. Kunihiko, Taniguchi ken-ichi Ito. Regional programme to promote technology transfer from the public sector to private sector: Proceedings of the Portland International Conference on Management of Engineering and Technologies, Portlant Oregon, USA, July 2000. pp. 27-31.

2. Ding, Junzheng & Motwani, Jaideep. Transfer of technology: A critical element in China's privatisation process. *Int. J. Technol. Manage.*, 2001, **21**(5/6), 453.

3. Indiresan, P. V. Transfer of technology. *Yojana* 31 December 1991.

4. Rao, H. S. Management of technology transfer from laboratory to industry. *Indian Management*, November 1988.

5. Allen, T. J. Managing the flow of technology, technology transfer and the dissemination of technological information within the R&D organisation. MIT. Pr., 1978.

6. Burgelman, R. A.; Maidique, M. A. & Wheeluright, S.C. Strategic management of technology and innovation. Mc-Graw Hill, Irwin, 2001.

7. Betz F. Strategic technology management. Mc-Graw Hill, New Delhi, 1994.

8. Mogavero, L.N. & Shane, R.S., What every engineer should know about technology transfer and innovation, edited by William H Middendorf. Mercel Dekker, Inc.

9. Eranst & Jrankel. Management of technological change. Kluwer Academic Publishers, London, 1990.

10. Mar, W.; Newell, W.T. & Saxbery, B.O. Managing high technology: An interdisciplinary perspective. N. V. North Holland, 1985.

**Contributors**

**Dr VSC Bose** obtianed his PhD from Indian Institute of Science, Bangalore in 1980. He is a senior Scientist, presently working in the Technology Transfer Group at the Defence Research & Development Laboratory (DRDL), Hyderabad. He had published several papers in the area of double-base propellants. Currently, his work focuses on technology transfer of missiles developed under Integrated Guided Missiles Development Programme (IGMDP). He has worked from 1973 to 1983 on solid rocket propellants at the Solid Propulsion Division of DRDL. Also, he is an IPRs Coordinator for DRDL and assists scientists for taking intellectual property rights. His research interests inclucde: International technology transfer management and effectiveness and management issues on IPRs.

**Mr V Krishna**, obtained his MTech (Metallurgical Engg) from IIT Mumbai, in 1962. For the past 25 years he has been working in the field of missiles, at the DRDL. He has been working as Head, Technology Transfer Group, DRDL for the past 10 years. He has experience in fabrication of missile components and assemblies. As Head of Technology Transfer Group, he has acted as an integrator between project team, designers and production and inspection agencies for successful transfer of technology for missiles and ground systems under concurrent development and production programme of IGMDP. He has evolved an effective methodology for technology transfer for successful productionisation of weapon systems. His areas of work include: magnetic materials, technology transfer of missiles, fabrication of missile components and assemblies.