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EXPERIENCE FROM THE CONSTRUCTION AND OPERATION OF TARAPUR AND RAJASTHAN NUCLEAR POWER STATIONS

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INTRODUCTION

Nuclear development has clearly emerged as a basic element in national strategies of growth, even in developing countries. In fact, it needs a well defined long-term national strategy of its own. In India, such a strategy enabled adequate groundwork to be done, from training of engineers and scientists to gaining familiarity with nuclear processes and equipment, to permit a 'go' decision around 1960 on the Tarapur (TAPS) and Rajasthan Atomic Power Stations (RAPS).

The primary objectives of TAPS differed from those of RAPS in one important respect. Whereas TAPS was basically intended to demonstrate the economic and technical viability of commercial nuclear power in India and provide basic operational experience, the emphasis in RAPS was on its being the first step in India's long-term nuclear power programme, one based on natural uranium and indigenous capability. This difference manifested itself in a turnkey contract being awarded for TAPS through global tenders unrestricted by reactor systems. Significant indigenous involvement was thus deliberately restricted to design review, commissioning and operational phases. A reasonably strong base of Indian personnel for operation and maintenance of LWR's was, however, created.

Approach for RAPS called for developing Indian capability in almost all areas of designing, manufacturing, building and operating a PHWR station. Import of technology and assistance was geared to these objectives and started tapering off in the beginning of 1970's and concluded soon thereafter.

The experiences of the two projects should be considered in this frame of reference.

THE TARAPUR EXPERIENCE

BACKGROUND

TAPS, India's first atomic power station has two GE first generation dual-cycle Boiling Water Reactors, sustaining a stretched output of 210 MWe each. The station which commenced operation in October 1969, is located about 100 Km north of Bombay on the sea coast and is integrated with the Western Regional Grid.

DESIGN PHASE

Detailed design of the power station, contracted as a turnkey project, was done in USA and reviewed by Indian Engineers. This consisted of safety review, review of plant layout, process piping design, specifications of equipment, follow-up of manufacture and inspection. Even though the designs were finalised early in 1963, subsequent changes that took place in BWR technology were incorporated to the extent necessary and feasible. Such changes concerned design pressure in the suppression pool, shutdown cooling system capacity, pressure suppression facility, etc. and some significant changes in material, such as for feedwaters. A unique feature resulting from design review was the use of LPRM's for local flux monitoring.

CONSTRUCTION PHASE

Though Indian Engineers and technicians were employed, supervision of construction and erection of critical equipment was by the main contractor's expatriate specialists. Indian made equipment were used to a limited extent.

Transportation of heavy equipments from U.S.A. deserves special mention. Detailed study revealed that the most convenient mode was transportation by sea right upto the site. An off-loading facility at site was established for a special shallow design barge which was used to transport all these heavy components.

Planning of construction which commenced in October 1964 was detailed and no major hardships were encountered. By early 1968 major systems had been successfully tested. Process piping had been chemically cleaned and flushed. Fuel loading plans were under review. However, stress corrosion cracking of stainless steel 304 reactor vessel cladding and components of primary system like that observed on a similar job abroad, was observed and required extensive repairs and replacement of some components. The secondary steam generator tubes were changed from stainless steel 304 material to 304L grade at site. Although these rectification works extended the construction period about a year, the station startup testing and warranty tests were completed satisfactorily in October 1969.

Construction of TAPS established the fact that nuclear stations can be built in a developing country in less than 5 years, provided equipment deliveries are satisfactory, experienced contractors are available and project management is highly result oriented.

OPERATIONS PHASE

During its seven years of operation, Tarapur, which has early generation reactors, has witnessed a number of design improvements and a variety of operating regimes and has built up an extensive maintenance capability.

Design Improvements

TAPS is the first twin-unit nuclear station in which some safety-related components and services are common to both units. Rather elementary application of this approach at TAPS has hampered satisfactory testing, maintenance, refuelling and operations. Furthermore, the early (1963) station design gave inadequate consideration to accessibility for inspection, surveillance and maintenance particularly in active areas. Operating experience had also shown deficiencies in performance of certain critical systems. Finally, operating standards have been tightened universally. All these required a series of design improvements, modifications and augmentation. By October 1976, 242 major and minor modifications had either been completed or were in progress.

Some Operational Highlights

Two major problems were observed when Unit 1 was opened for its first refuelling; failure of incore monitor housing bracings due to vibration induced stresses and drifting of one of the guide tubes caused by a design deficiency. The damaged bracings were cut by underwater tools, some of them locally improvised. Modifications were also carried out on thermal sleeve hold-down devices for all the guide tubes. The process was repeated on the second unit. The remarkable feature about these major problems, not abnormal in an evolving technology, was that they were resolved almost entirely by our own efforts.

Maintenance & Refuelling

Procurement of imported spares and components is a major maintenance problem for various reasons, including obsolescence. Recourse to repair equipments to much greater extent than normal and rigorous drive for import substitution have been imperative. For instance, the original event sequence recorders were replaced by those of better design made at Bhabha Atomic Research Centre. Similarly a number of underwater handling tools and equipment have been found necessary and fabricated locally for satisfactory refuelling operations.

With regard to refuelling-cum-maintenance outages, TAPS experience shows their critical dependence on availability of trained manpower. In the absence of support from trained crews from vendors or experienced maintenance contractors which are rarely available in developing countries, considerable effort has been expended in obtaining and training men from other units of the Department of Atomic Energy as well as from thermal utilities and even from the Armed Services. These handicaps, apart from simultaneous need to resolve even complex technical problems locally render refuelling and major maintenance tasks very demanding and have occasioned some interesting management responses. Gradual and significant reduction in refuelling period achieved indicates the measure of experience and competence acquired.

Fuel Performance

Inadequacies in design and fabrication processes of early fuel caused failures which left many areas in the plant rather active and gave rise to maintenance problems. Besides, high off-gas activity imposed output restrictions. The cyclical operation of the reactor plant required by the power grid induced additional fuel failures. Preconditioning of fuel during startup and initial power raise since 1975 has reduced fuel failure rates as shown in fuel cycle data (Table I). The improved type fuel of 6 x 6 design is presently made in India.

Grid

The need for a stable electrical grid with adequate base load and spinning reserves is emphatically brought out by TAPS experience. Gujarat's share of TAPS output formed some 30% of the State's then total installed capacity. The rather small size of the grid created operational difficulties even with the 210 MWe units. In the early months, deficiencies in the switchyard (not then under Station control) caused many unit outages. Subsequently, daily output variations were imposed by grid demand fluctuations which contributed to fuel failures. Lack of spinning reserve capacity in the grid, a persisting handicap, has frequently compromised satisfactory maintenance. Operation at off-standard frequency is also not unusual, again due to inadequate system capacity. In 1973 unusual monsoon caused extensive malfunctioning of the transmission system subjecting the station to repeated total loss of power situations and consequently shock induced deficiencies. All these have affected station performance and necessitated extensive remedial measures.

Overall Performance

Tarapur has now gained about fourteen reactor years of operating experience with seven refuelling outages completed by the end of October 1976.

The lifetime capacity factor of TAPS was 47.7% upto June 1976. However, performance since mid-1974 has improved significantly. Forced outages have also reduced sharply, there being none on Unit 1, and only 3 on Unit 2 with a total duration of 14 hours, in 1975.

The principal gain from TAPS operational experience has been the confidence acquired through month after painstaking month of engineering design modifications, devising locally suitable tools and operation procedures and making do with a minimal level of external services from vendors and contractors.

THE RAJASTHAN EXPERIENCE

BACKGROUND

Rajasthan Atomic Power Station has two PHWR units of 220 MWe each with on-load fuelling and is connected to 220 KV Northern Indian grid. It is situated on the Rana Pratap Sagar Reservoir in a virtually uninhabitated and undeveloped area, nearest town and railhead at Kota being 80 Kms. away. Preliminary site investigations and preparations were started in 1963 and the main plant construction in 1965. Equipment erection was taken up around 1967; the first Unit became critical in August 1972 and went in commercial operation in December 1973. The second unit is in the final stages of construction.

DESIGN PHASE

A joint Canadian Indian Study conducted in 1962 determined the feasibility of this project and amount of Indian participation then possible. Initially designs, procurement etc. were through Canadian Consultants. Indian Engineers were seconded to work with the designers to acquire experience. Participation was gradually increased on Unit 2 as manufacture of more and more equipments was undertaken by Indian firms. These enabled engineers to acquire experience in the areas of specification preparation, tender evaluation and liaison with manufacturers for fabrication detailing, inspection and particularly in consideration of design concessions. This ultimately led to the establishment of the Power Projects Engineering Division capable of independently designing and engineering subsequent nuclear stations.

CONSTRUCTION PHASE

Evaluation of RAPS construction experience brings into focus both the real and multifarious obstacles inherent in a developing economy, and the fact that these can be overcome.

Construction Management

This was retained with the Department of Atomic Energy. While experienced Indian contractors were employed for civil, piping, electrical and other works, erection of complex nuclear components requiring special skills and precautions was done by departmental personnel.

Transportation of Heavy Components

Remoteness of the site created the problem of transporting large and heavy equipment. Rail consignments were transported to Kota. Heavy consignments were then transported to site over hilly roads with many difficult bends and curves. Components considered overdimensioned for rail movement were brought from Kandla port to site by tractor-trailers covering a distance of some 1000 Kms. Roads needed extensive repairs and modifications involving strengthening of bridges and culverts or constructing by-passes. Restrictions to movements during winter in Canada and during monsoons in India created limitations on ODC shipping and problems in project planning.

Civil Works

These were generally to heavy construction standards. Stringent supervision and quality control on concrete mixes was exercised, specially for the Reactor Building which also acts as a containment vessel. Mock pours were conducted before satisfactory method was approved in important areas where concrete placement was very difficult.

Reactor Erection

DAE had already acquired skills in installation of research reactors at Trombay and therefore undertook nuclear erection at RAPS itself. RAPS equipment was however considerably larger and more complex. Work involved moving, installation and ultimate alignment of nuclear components of large dimensions ranging from 31 tonnes to 122 tonnes (Table II). Special training of skilled workmen on improvised methods, tools and jigs had to be resorted to. Many components required further work after arrival, such as Calandria tube rolling, installation of high pressure tubes and end fittings of PHT system and welding of difficult components. Such works were undertaken for the first time in India and entailed training on mock-ups to meet stringent requirements of helium leak tightness and close alignment tolerances.

General Mechanical Erection

While no special troubles were encountered, those inherent in contractors undertaking nuclear grade work requiring stricter codal requirements for the first time in a developing country did need special attention. On some occasions the Project took over such jobs by enlarging its site workshop and reworking some components.

Piping installation was contracted to a firm experienced in high pressure/temperature thermal station. Here again, because of lack of experience in nuclear piping works and not enough appreciation of the complexities of the piping systems, plus the exacting quality control which included helium leak tightness of the heavy water system, contract ran initially into trouble and was further aggravated by delays in supply of components, materials, consumables, etc. With timely action the contract was set right and with experience gained, RAPP-2 contract was successfully accomplished.

OPERATIONS PHASE

Unit availability factors since commencement of commercial; operations in December 1973 were 58% in 1974 and 45% in 1975. Although output has been relatively low until mid-1976 a wealth of operating experience in PHWR systems has been acquired. Necessary rectifications have been carried out in 1975 and 1976 and the Unit has operated steadily since then.

Turbines

Almost two-thirds of the unavailability was due to problems with the imported turbine, first with bearings and followed by fatigue failures of H. P. blades due to resonance and finally a random type LP blade failure.

PHT System

Some 23% of unavailability stemmed from the primary heat transport system due to constraints associated with PHT motors. Partial blockage of some of the coolant channels resulting from failure of components in the PHT system check valves was identified radiographically and subsequently removed. The practice of freezing heavy water prior to cutting the lines to gain access to the heavy water systems has been established satisfactorily.

Moderator System

System has performed well except for some problem relating to formation nitrate/nitrites and high conductivity resulting in excess deuterium concentrations in cover gas. Modifications in the ion-exchange circuits have now eliminated these problems.

On-power Refuelling

Bi-directional on-power refuelling facility provided at RAPS has generally performed satisfactorily excepting for some problems of a mechanical nature. Strict quality control during fuel manufacture and pre-loading inspection has led to excellent fuel performance.

Grid

Initially the station was linked with a small grid and faced a series of problems. Later with interregional link-up, the size of grid went upto 5000 MW and conditions have substantially improved although off-standard system frequency and severe voltage fluctuations continue to affect station operations.

Manpower

Recruitment and training of skilled manpower has been one of the dominating factors in the Rajasthan experience. A nationwide recruitment effort was necessary to obtain reasonably skilled personnel from industries like steel, chemicals and fertilizers. Many key personnel came from DAE's other nuclear Units. For operations staff, men were drawn from our research reactors and the country's thermal utilities.

Training for construction was needed mainly for specialized nuclear components, contractors providing largely for work in other areas. That for O & M, however, needed much greater attention. A well-equipped Nuclear Training Centre was set up very early at site, supplementing training for professionals imparted at the Bhabha Atomic Research Centre. NTC is now being augmented with an Operations Simulator costing around US $ 3 million and based on indigenously made computers.

CONCLUSIONS

From the above it will be clear that both TAPS and RAPS provide excellent case studies of a developing nation's initial efforts to assimilate an advanced technology on a commercial scale.

Of the principal points that emerge from these case studies, perhaps the most vital are the needs for a long-term national commitment, and a base of skilled manpower. These provide the brains, brawns and means not only for resolving a series of unusual problems that a project in such circumstances inevitably faces, but also for a sustained growth in this vital field.

TABLE I

TAPS FUEL CYCLE PERFORMANCE

Description	Unit 1			Unit 2			
Cycle	1	2	3	1	2	3	4
1. Operating Period	Beginning to Aug. '71	April '72 to Jan. '73	May '73 to Jan. '75	Beginning to March '72	Dec. '72 to Feb. '74	July '74 to July '75	Oct. '75 to July '76
2. Core average exposure : MWD/ST							
Beginning of cycle	0	5,976	4,469	0	6,656	8,348	8,779
End of Cycle	7,551	8,242	9,630	8,446	11,256	11,878	12,491
3. Average Irradiation Level MWD/ST	8,672	10,080	14,479	9,775	12,063	12,945	17,545
4. Cycle Length : MWD	328,021	98,427	225,462	368,492	199,689	153,719	161,956
5. Cycle electricity Generation, MWh	2311122	730156	1578144	2634523	1439432	1058548	1134076
6. Cycle capacity factor %	52.8	52.8	51.4	49.7	66.2	59.8	79.8
7. On Line : Hours	15647	5661	11957	18038	8789	6817	6480
8. Cycle Availability factor %	75.0	85.9	81.8	71.5	84.9	80.8	95.8
9. No. of leakers found at end of cycle	52	118	98	49	83	57	19

Note :- For Unit 1 Cycle 4 is in progress since May 1975 and Unit 2 Cycle 5 since October 1976.

TABLE II

MAJOR NUCLEAR COMPONENTS ERECTED

	Component	Approx. Weight	Dimensions
1.	End Shield rings (2)	31 Tonnes each	6000 mm OD (Max.) - 5080 mm ID x 812.8 mm wide.
2.	End Shields (2)	122 Tonnes each	5080 mm OD x 1117.6 mm thick.
3.	Calandria	71 Tonnes	6.096 M dia - 3.304 M long.
4.	Dump Tank	102 Tonnes	7.925 M x 5.182 M x 3.200 M.
5.	Shield Tank	102 Tonnes	8.230 M x 5.182 M x 3.962 M.
6.	Expansion Joint	1 Tonne	2972 mm OD convolutions - 2642 mm skirt x 609.6 mm long.
7.	Steam Generators (8)	51 Tonnes each	9.760 M - 6.506 M - 2.998 M.