The Challenge of Developing a High Speed Rotor Assembly - How It Was Met

Shri R.K. Garg, FNAE

Preamble

The development of a high speed rotating machine commonly known as 'Gas Centrifuge' and used in enrichment of Uranium is considered a difficult and guarded technology, but strategic for the nuclear energy programme. This was achieved in the Bhabha Atomic Research Centre (BARC) during the period 1980–1990 by entirely indigenous R&D efforts. For me, as a leading participant in this development, right from conception to the final stage, it was both, a challenge and unique opportunity which not many engineers get throughout their professional career. I take pride in sharing with fellow engineers and scientists my experience and my belief that for a dedicated team, no task is impossible if the right working environment is provided.

Being a multi- disciplinary project, the R&D team comprised of about twenty engineers and scientists in the disciplines of chemical, mechanical, electrical, electronics and instrumentation engineering, metallurgy, physics and chemistry. One unique feature of this team was that except two of us, all others had joined directly from the Training School run by BARC to work on this project. The credit for the success of this project goes to all of them who worked with dedication and team spirit and employed several innovative ideas.

Glimpses of some of the materials, components and systems needed for this programme and the technological and managerial approaches that were adopted for this development, leading to the setting up of a demonstration facility, are provided in this article.

1. **Introduction**:Right from the inception of the nuclear energy development programme, started immediately after independence under the leadership of the visionary Dr. H.J. Bhabha, the focus has been on achieving indigenous capability for harnessing this new source of energy. Towards this end steps were initiated for training of manpower, production of special materials required and development of relevant technologies. For those not familiar with the basics of nuclear power, it may be worthwhile to mention that whereas in a thermal power plant, coal, oil or natural gas is burnt in the boiler for raising steam which runs the turbine, in a nuclear power plant uranium is used as fuel in the nuclear reactor to generate heat. Uranium, thus, becomes the essential material for the nuclear power programme. Moreover, unlike coal, oil or gas, uranium as it occurs in nature is mined as an ore and has to go through a number of processes to make it usable in a nuclear reactor. After use in the reactor, the spent fuel has again to be processed or managed with great care due to very high level of radioactivity in it. The processing of the spent fuel also gives plutonium, a man-made material which again can be used as fuel in a

nuclear reactor. Uranium as it occurs in nature has only 0.7% of U^{235} isotope which is fissionable and serves as fuel in the reactor, the bulk (99.3%) being U^{238}. Nuclear power reactors can use uranium in natural form (but need heavy water as coolant) or enriched in U^{235} to the extent of 3-4% where ordinary water can be used as coolant. For some special types of nuclear reactors or for use in nuclear weapons much higher enrichments are required. All the steps for producing fuel for nuclear reactors constitute what is known as the 'Nuclear Fuel Cycle'. Needless to say, the development of technologies for the fuel cycle is the most important pre-requisite for a successful and hurdle free nuclear power programme. These technologies are not easily available and some of them viz. uranium enrichment and plutonium extraction from spent fuel, not available at any cost.

2. **Back ground**:By about 1970 India had in operation two nuclear power reactors imported from USA fueled with enriched uranium. Two natural uranium Heavy Water cooled reactors were under construction with collaboration from Canada. Two research reactors, one based on natural uranium and the other on enriched uranium, had been operating for over 10 years. Based on R&D efforts in BARC, processes for extraction of uranium from ores, conversion of the uranium concentrate to metal or oxide of nuclear purity, fabrication into fuel elements for use in research as well as power reactors and for extraction of plutonium from spent fuel, had been developed and production plants had been setup or were in an advanced stage of construction. Processes for heavy water production were also under development. Thus, indigenous technologies had been developed for all the steps of the fuel cycle except uranium enrichment. Even preliminary studies had not been initiated. It was thought that uranium enrichment was a difficult technology and highly capital and energy intensive. At that time enrichment plants were operating only in the USA, Russia and France. These plants were based on the 'Gaseous Diffusion' process, using uranium hexafluoride as the gas for isotopic separation.

Around this time some reports appeared about another process viz. 'Gas Centrifuge' being developed jointly by UK, Netherlands and Germany. In Germany 'Nozzle Separation' process was also being pursued.

Difficulties in the separation of isotopes of an element arise due to the very small difference in the physical and chemical properties of the isotopes or their compounds more so for heavy elements like uranium. A very large number of stages are required for meaningful separation. Studies on separation of some of the isotopes of light elements like Hydrogen (for Heavy Water production),Boron and Nitrogen were already in progress in BARC. These processes were based either on difference in the physical properties or the chemical exchange behavior. A small plant for separating deuterium and hydrogen by electrolysis of water had been operating at Nangal as an adjunct to the fertilizer plant.

3. **Initiation of Studies on Uranium Enrichment**: With the status of development summarized above and with the confidence gained in development of technologies of the other nuclear fuel cycle processes, when the plans of the department of Atomic Energy were being prepared for the decade 1970-1980, it was proposed that preliminary studies may be initiated on uranium enrichment as well. By this time, two other projects in which I was the leading participant were nearing completion. I, therefore, got the opportunity to

take up R&D studies on this topic. To start with, a project team was constituted in 1970 with three fresh engineers from the training school of BARC. Over a period of 6-7 years the team size increased to about twenty engineers and scientists in various disciplines, all fresh from the training school.

It was decided to simultaneously carryout literature (whatever little was available) survey and feasibility studies of all the processes reported to be in use for production and those under development in other countries of the world. The processes in these categories were the 'Gaseous Diffusion', Gas Centrifuge, Nozzle Separation and Chemical Exchange. Separate groups were constituted for study of these processes. For the first three processes the feed material has to be in the gaseous state viz. uranium hexafluoride. So a separate group was given the task of developing the technology for its production. It involved production of fluorine gas as well, since it was not available in the country. The technology for production of uranium tetra fluoride was already established.

On the analogy of deuterium enrichment (for heavy water production) by chemical exchange, experimental work on the chemical exchange process for uranium enrichment could be started immediately. However, after trials with a few systems over a period of about 2 years no meaningful results could be obtained. The separation factors are perhaps quite low, requiring a very large member of stages to get enrichment which could be detected by the mass spectrometer available in BARC at that time. This approach was, therefore, not pursued further.

The other three processes based on the small difference in the physical properties of the molecules of the isotopes ofU^{235} and U^{238} require, first, the development of the separating element (diffusion membrane, nozzles with very small opening or very high speed rotating cylinder). Each one requires different materials and fabrication technology. Other equipment and components required for these processes include compressors / vacuum pumps, valves, instrumentation, piping, heat exchangers etc. All items have to be compatible with uranium hexafluoride (UF6) which is a corrosive gas. Moreover, in view of the properties of UF6, the whole system has to work under sub-atmospheric pressure, and is required to have high level of leak tightness. Studies on the three processes continued over a period of 7-8 years to evaluate and assess the technical feasibility of making the separating elements based on laboratory scale work, survey of availability of required materials and equipment in the country or abroad freely, special fabrication facilities, if any, to be established etc. The costs and the time frame for the first prototype and the possibility of scale up subsequently were also taken into consideration. Based on the outcome of these studies, the 'Gas Centrifuge' process emerged as the choice for further development and all efforts were directed towards it.

4. **Development of the 'Gas Centrifuge' Process**: After preliminary studies, the following plan of action was prepared:

i) Development of the rotor assembly (centrifuge) consisting of

(a) a tube of suitable length and diameter capable of rotating at a peripheral speed of at least 300 m/sec- which means made of material with high specific strength, and having other suitable mechanical properties, resistance to corrosive action of UF6, and thin enough to reduce the power required for its rotation.

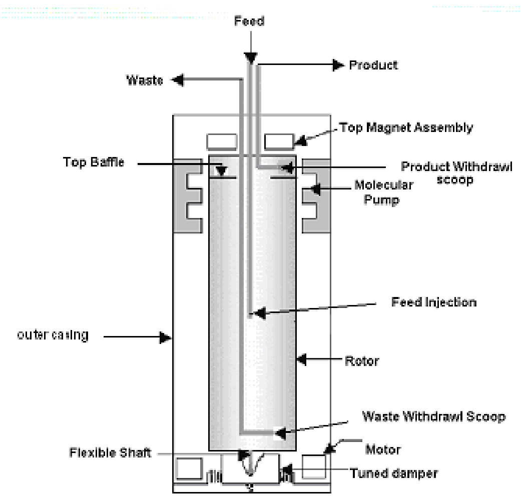
(b) high speed motor for long continuous run, and a stable high frequency power supply source for the motor.

(c) a bearing and suspension system to support the rotor and to ensure dynamic stability at high speeds.

(d) a casing to protect against crash of the rotor and to maintain high vacuum to eliminate drag loss.

(e) provision of facilities for electron beam welding, heat treatment, passivation, plating, dynamic balancing etc.

(f) Arrangements for feeding the UF6 gas and removal of the separated streams. A conceptual design of the centrifuge is given in the diagram.



Schematic diagram of a Gas Centrifuge

ii) Sourcing or providing special materials and manufacturing facilities to produce the above components, in large numbers- initially in hundreds and subsequently in thousands.

iii) Interconnection of the units in parallel as well as in series mode through a network of pipes and valves and sourcing of other equipment like vacuum pumps, condensers and instrumentation for monitoring and control.

From the survey carried out, it was apparent that none of the components of the rotor assembly would be available off the shelf and everything would have to be developed ab initio. Each member of the team was assigned the task of developing a specific component or system. He was given the freedom to select his line of action and to obtain guidance or help from any source he considered necessary, within BARC or outside. I acknowledge the full support of various groups in BARC and my seniors in the execution of this project.

The first important decision to be taken was on the material to be used for the rotor tube, taking into consideration the possibility of its availability indigenously or from outside sources as unrestricted supply and facilities for fabrication into tubes of the required dimensions. The candidate materials having high specific strength (Tensile strength/density) were identified as certain aluminium alloys, titanium alloys, high strength steels, maraging steel and fibre-resin composites. It was learnt that Midhani was in the process of developing certain grades of maraging steel for application in defence and the space research programmes. Maraging steel was, therefore, selected as the material of the tube. To get the tube of the required dimension, the product from Midhani had to go through two fabrication steps viz extrusion to make the blank tube of a higher thickness followed by flow forming to the required dimensions and wall thickness. It was foundthat at that time only one flow forming machine was available in the country, with a Govt. organization and a private party was intending to import a similar machine for making cans. The machine imported by the Govt. organization had not been installed. The private party was, therefore, encouraged to import the machine as early as possible. Thus, three organizations were identified and contact established to ensure procurement of the tube-Midhani for the maraging steel material, Nuclear Fuel Complex for extrusion of the blank and the private party for flow forming. Facilities for other operations like welding the top and bottom discs to the tube by electron beam welding, dynamic balancing, heat treatment, passivation etc. were set up in-house. The EB welding machine was developed by a separate group in BARC.

The motor to drive the rotor at a constant speed of 40000-45000 rpm was the next major component which had to be developed. The power rating was arrived at through design calculations and experimental studies. Motors with wound rotors were ruled out due to mechanical reasons. The choice narrowed down to hysteresis type solid rotor motors. Further, to eliminate any radial loading due to radial magneticflux, axial flux motor was envisaged. Thus, a unique motor design was developed with the stator in the shape of a pancake and rotor disc directly attached to the bottom end of the rotor disc. The material of the motor rotor had to be optimized taking into consideration mechanical strength and hysteresis properties. The motor stator had also to be potted to guard against corrosion. A high frequency drive was also needed to convert the 50 Hz supply to 700-800 Hz to run the motor at 40000-45000rpm. For initial trials various sources were rigged and finally low power switching inverters were developed. One of the groups in BARC greatly helped in this endeavour.

Non-contact pickups and associated instruments for measuring the speed and vibrations were also developed, since none of these were available in the market.

The other critical component which had to be developed was the bearing to support the long rotor. The bearing had to work in vacuum, was subjected to axial as well as radial load of a few kgs., had to run at very high speeds, continuously for years without any maintenance or lubrication. No available bearing could meet such stringent conditions. Design and fabrication of the bearing had, therefore, to be taken up in-house. After studying various systems, a hybrid design of a pivot and jewel bearing incorporating hydrodynamic action was adopted. Spiral grooves were made on one of the bearing surfaces which would generate a fluid film between the two surfaces and ensure a long life. A stable hydraulic fluid with very low vapour pressure had to be selected and procured. The problem of machining of the pivot and the jewel to the required sub-micron tolerances and engraving the spiral grooves had also to be tackled. Some enterprising entrepreneurs were roped in to undertake this job. To reduce the load on the bearing and for radial stability, a magnetic suspension system was incorporated.

By 1983 the above efforts enabled us to make the first prototype unit which could run at speeds close to the target and on which some separation trials could be conducted using some gas mixtures. This was followed by isotopic separation using the process gas viz. UF6 which by that time could be made on a small scale. A few more units were then assembled and connected in series to partly simulate the conditions of a cascade. A semi pilot scale facility was, thus, available for component and system testing and for conducting separation trials. Concurrently a decision was taken to set up a demonstration plant with a few hundred units. A new site was selected and civil construction work started in 1984. Along with experimental work in the semi pilot plant and construction work of the demonstration plant buildings, activities connected with sourcing of materials, fabrication and machining , procurement of bought out items had to be intensified.

The demonstration plant was planned to have a cascade consisting of a few hundred rotors to start with, facilities for testing of components and assembly of rotor components as well as for UF6 production. By 1989 all the construction activities and installation work were completed and the plant was commissioned with UF6 process gas and enriched uranium was produced in the country for the first time in kg quantity. A venture which appeared to be fraught with many uncertainties became a success story and a matter of pride for all of us who were participants in it. It was possible due to the full commitment and dedication of the team, their untiring efforts and innovative approach and co-operation of many groups in BARC.

With the successful completion of this project, I retired in 1990 with a sense of satisfaction and fulfillment and with the firm belief that determination to achieve the goal, confidence in oneself and the team members and hard work are the keys to the success of any venture.

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