Journey from scarcity to surplus-success story of India's Heavy Water Production

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Preamble

Since 1962, India has had Heavy Water Production for achieving the goal of nuclear power production based on reactor designs that use natural uranium and Heavy Water. Although the path that led to success was not smooth, India matches the footsteps of the developed countries in the technology for production of Heavy Water.

Through this article, an attempt has been made to unfold the story behind the success of Heavy Water production in a sequential manner as far as possible in the backdrop of science and technology challenges, research and development activities and acknowledging the contribution of our pioneers. This is the story of our challenging past to competent present carving the path towards a sustainable future.

In this article we will see how integration of the knowledge of basic sciences with various branches of engineering led to successful development of technology for production of Heavy Water in India.

A. Introduction

The discovery of deuterium by Prof. H.C. Urey in 1931 was a key event in the history of science for which he was awarded Nobel Prize in the year 1934. In Urey's Nobel lecture, delivered on February 14, 1935, he stated that;

"The discovery of deuterium and the marked differences in the physical and chemical properties of hydrogen and deuterium, together with an efficient method for the separation of these isotopes, have opened an interesting field of research in several of the major branches of

science. It is my expectation that the next few years will witness the separation of the isotopes of the lighter elements in sufficient quantities for effective research in chemistry, physics and biology. If this can be effected, the work on deuterium is only the beginning of a very interesting scientific development."

After a couple of years of the above statement, considerable interest in heavy water was aroused in 1939 when Hans von Halban and Lew Kowarski suggested that heavy water could be used as a neutron moderator in a nuclear reactor using natural uranium. The Manhattan Project's heavy water production programme was taken up in the codename P-9 Project. Under this project P-9, the Cominco operation at Trail, British Columbia, took up the activity to produce heavy water. Also, DuPont built three plants in the United States between 1943-1945.

Heavy water availability was a problem due to its scarcity, and thus required quantity was not available for reactors. Urey's mentor Gilbert Newton Lewis could generate pure heavy water in 1933 using electrolysis. However, the economics of this process was not great. In subsequent years, water electrolysis, water distillation and hydrogen distillation were investigated as potential hydrogen-deuterium separation processes. During World War-II, USA and Germany exerted extensive efforts to evaluate and develop potential heavy water production processes. Two promising chemical exchange processes identified as : water-hydrogen and water-hydrogen-sulfide. The water-hydrogen process became basis of the first industrial scale plants for heavy water production at a reasonable cost. The water-hydrogen-sulfide, eventually known as the GS process, became basis of large scale heavy water plants.

Karl-Hermann Geib in Leuna in 1943 developed what we know as the dual temperature sulfide exchange process which is cost effective process for Heavy Water production. Contemporaneously, the process was also developed by J.S. Specvack at Columbia University and his process became the basis of the post war North-America plants under the name of the Girdler Sulphide (GS) process named after the company which first exploited it.

The method is an isotopic exchange process between H_2S and H_2O which is highly energy intensive for production of heavy water.

Throughout the fifties and sixties, many processes were considered, and few were taken up for laboratory investigation in pilot plants, but only a handful were adopted for production of heavy water.

Major research and technology development for heavy water production has been carried out by nearly all the countries that built prototype heavy water power reactors like Canada, France, Germany, India, Italy, Sweden, Switzerland and United Kingdom. Despite this large effort involving hundreds of man-years by chemists, physicists and engineers, no other method has reached the stage where it can challenge the GS process as the major source of heavy water.

Until its closure in 1997, the Bruce Heavy Water Plant in Ontario (located on the same site as Douglas Point and the Bruce Nuclear Generating Station) was the world's largest heavy water production plant. It used the Girdler sulfide process to produce heavy water, and required by mass 35000 units of feed water to produce 1 unit of heavy water.

The first such facility of India's Heavy Water Board to use the Girdler process is at Rawatbhata near Kota, Rajasthan. This was followed by a larger plant at Manuguru, Andhra Pradesh. Other plants exist in the United States and Romania for example.

Another viable process of deuterium isotope separation is ammonia-hydrogen exchange process using potassium amide as catalyst. In this process, ammonia synthesis gas (which is mixture of Hydrogen and Nitrogen) is the deuterium source and it is commonly known as mono-thermal ammonia-hydrogen exchange process, first used at Mazingarbe in France. Based on this, two heavy water plants are installed in India.

Urey's prediction proved true over the years since after the discovery of deuterium and in present times, basic science on deuterium has shifted towards development of various technologies utilizing the potential non-power applications of deuteriumin in various fields viz. pharmaceutical , spectroscopy, semiconductor, optical fibre etc.

B. Heavy Water Programme of India and Heavy Water Board:

Dr. Homi Jehangir Bhabha, architect of Atomic Energy Programme in India, laid the foundation of an integrated three-stage nuclear power programme. His vision led to India pursuing an ambitious nuclear programme comprising of R&D and industrial deployment with significant societal benefits.

Recognizing the fact that India has limited uranium resources but rich thorium reserves, Bhabha formulated a three-stage nuclear power generation programme, which has been discussed in chapter on Nuclear Power in India.

The success of first phase of Indian Nuclear Power Programme (INPP), using natural uranium as fuel and Heavy Water as moderator, was depending on timely and sustained availability of Heavy Water for PHWRs. Heavy Water Board (HWB), a constituent unit (I&M) under Department of Atomic Energy, is the sole agency in the country mandated for production and supply of Heavy Water for the INPP.

The first Heavy Water Plant was set up at Nangal based on electrolysis followed by cryogenic distillation of Hydrogen.

Industrial plants set up at Baroda and Tuticorin based on Ammonia Hydrogen mono-thermal exchange process has led to successful indigenous deployment of second generation plants at Thal and Hazira. Hydrogen Sulfide - Water Bi-thermal exchange process (Girdler-Sulfide process) was indigenously developed starting from laboratory studies to pilot plant and breakthrough was achieved by setting up first industrial plant at Kota. The consolidation of process could be achieved by setting up a second generation plant at Manuguru.

HWB is fulfilling the growing demands of Heavy Water for Indian Nuclear Power Programme and after making the country self-reliant, it is also exporting high quality Heavy Water to countries like Republic of Korea, United States of America, France etc. for nuclear and non-nuclear applications. Presently, India is the one of the largest global producer of Heavy Water and is the only country using multiple technologies for production.

HWB has now diversified into other activities like industrial production of other nuclear materials required for first and second stage of nuclear power programme. These include Sodium and ^{10}B enriched Boron Carbide for fast breeder reactors, nuclear grade solvents used in front-end and back-end of nuclear fuel cycle, rare metal recovery from secondary sources by solvent extraction. HWB's mandate includes development and deployment of spin-offs, allied and separation technologies on industrial scale for lighter molecules in particular, like production of oxygen-18 enriched water, hydrogen, helium etc; identifying and promoting non-nuclear uses of Heavy Water/deuterium, as deuterium labeled compounds for industrial and medical applications.

C. Heavy Water Production for the first stage of INPP

i. Mission at Nangal

Heavy Water was essential for the first phase of the Nuclear Power Programme based on PHWRs. The production of Heavy Water had to be taken up on a large scale to match the projected nuclear power programme.

In early 1954, when DAE began exploring the feasibility of producing Heavy Water indigenously, it considered two processes viz., electrolysis of water and distillation of water. The electrolysis process economics were analysed for the scenario of Heavy Water being a stand-alone product and also a by-product of a fertilizer plant based on electrolytic Hydrogen. India's Heavy Water production programme thus took off with the decision to set up the first Heavy Water plant with 14 Te/Annum capacity at Nangal, Punjab. This was a very significant move as it exploited the available potential for production at an economical price and gave an early start to the Heavy Water Production Programme. The plant was completed and commissioned without any undue delay and India could produce first drop of Heavy Water on August 9, 1962 which remains a red-letter day in the history of indigenous Heavy Water production. This plant, when built, was the largest plant of its kind in the world. The plant continued to operate steadily until 1978. Since demand for power for alternate uses in the region was growing, the fertilizer plant had to switch over to an alternate method for production of Hydrogen, thus abandoning most of the electrolysis plant. Also with the successful development of the other technologies for production of Heavy Water at much lesser energy input, distillation of Hydrogen became an obsolete method for industrial scale production.

Heavy Water Plant, Nangal

ii. R&D at BARC

Heavy Water& Stable Isotope Production (HW & SIP) Section as part of the Chemical Engineering Division (CED) at Atomic Energy Establishment Trombay, AEET (later renamed as BARC) launched the indigenous effort by setting up pilot plants based on water distillation and dual temperature H_2S-H_2O exchange process for collection of data. Subsequently, a core group was constituted for working on process development, generating of flow sheet, sizing of equipment and for carrying out test loop studies for establishing suitability of materials and components for H_2S-H_2O based process. Several studies were carried out viz. measurement of surface tension, foaming characteristics of water saturated with H_2S, corrosion behavior, effluent treatment etc. Monitoring methods for H_2S and procedure for pre-conditioning of carbon steel, by formation of protective sulfide film were developed. Various analytical methods for analysis of deuterium were developed and standardized.

It was envisaged that the final enrichment in Heavy Water plant (HWP) would be carried out by the distillation process. To start with, a 1" dia column and later a 4" dia column with Dixon ring packing was set up and operated. Special type of ordered packing were developed by Heavy Water Division (HWD), BARC. The development of packing made of phosphor bronze wire mesh with corrugation led to sizable reduction in plant volume and capital cost.

iii. Journey from Scarcity to Self-Reliance – pursuing multiple technologies with success

Way back in 1956, Bhabha observed that ……..”*there was every indication that its (Heavy Water) uses in atomic energy are not likely to diminish*”. He, therefore, urged that, “*the production of Heavy Water should be maximized without hesitation*”. This was to set the course for the Heavy Water production programme.

In order to give a thrust to the Heavy Water production programme, on the eve of its entering the large industrial scale production era, on May 1, 1969, DAE created a separate unit known as “Heavy Water Projects Board” for managing the projects for the production of Heavy Water. On February 17, 1989 this unit was renamed as “Heavy Water Board” to bring it in consonance with the emphasis on the nature of the unit having shifted from projects to plants.

The H_2S-H_2O dual temperature exchange process was known to be the process employed for large-scale production of Heavy Water in the world. However, very little information and data were available about the technology. DAE, having pronounced preference and penchant for development of indigenous technology and philosophy of self-reliance, decided to develop this process virtually from scratch. Indigenous development became successful by setting up pilot plant based on water distillation and dual temperature H_2S-H_2O exchange process for collection of data. Rajasthan Atomic Power Station (RAPP) I and II at Kota were capable of generating about 10-15% of extra steam over the rated capacity which seemed to be an excellent opportunity for obtaining steam for Heavy Water production. Thus, it became evident that setting up of the Heavy Water plant in the close proximity of RAPP I&II would ensure, adequate electric power supply, meet the process steam requirements at lower cost, also vast source of water from Rana Pratap Sagar reservoir and required land were available at that site. This resulted in setting up of first H_2S-H_2O based Heavy Water Plant at Kota.

Heavy Water Plant, Kota

Another successful technology for large scale production of Heavy Water developed during 1957-1960 was mono-thermal ammonia-Hydrogen exchange. Around mid-1968, Gujarat State Fertilizer Co. (GFSC), Baroda had a large single stream ammonia plant. Thus it was decided to put up a Heavy Water plant integrating with GFSC plant. The plant produced Heavy Water for the first time in July, 1977.

Since the requirements of Heavy Water were pressing with the additional PHWRs, efforts were intensified for setting up the third Heavy Water Plant. This resulted in setting up of mono-thermal ammonia-Hydrogen based HWP in integration with the fertilizer plant of SPIC, Tuticorin. The plant was commissioned in 1978.

It came out that a bi-thermal Ammonia-Hydrogen exchange process developed by UDHE, Germany is more attractive than the mono-thermal process owing to the fact of inherent lower energy requirement. DAE approved the project of setting up a HWP based on this process at Talcher in integration with Fertilizer Corporation of India (FCI). Unfortunately, the fertilizer plant could not carry out satisfactory sustained operations at a reasonable load. The synthesis gas supplied by the fertilizer plant was seldom in adequate quantity and of required purity. With great deal of difficulty, HWB commissioned the plant and it produced its first drop of Heavy Water in October, 1984. However, the plant could not be operated on sustained basis at the required capacity.

Having had the cumulative experience of setting up, commissioning, de-bugging the technology and stabilizing the operations of Heavy Water Plants, HWP felt confident about setting up of two more mono-thermal ammonia-hydrogen based plant at HWP Thal and Hazira and one bi-thermal H_2S-H_2O based plant at Manuguru. HWB also set up a Captive Power Plant (CPP) to meet the power and steam requirement of HWP Manuguru.

Heavy Water Plant, Manuguru

iv. Export

By 1990's, after becoming self-sufficient vis-à-vis domestic requirements, the scenario changed to that being surplus in Heavy Water and being in a position to sell too as was dreamt by Bhabha.

An opportunity for export came when the South Korean company Korea Electric Power Corporation (KEPCO) wanted HW for their PHWR. India thus got a foothold in the international market as an established supplier of HW. HWB won accolades from South Korea for the quality of HW supplied. As fulfillment of Bhabha's dream, HWB could establish itself as a major supplier in the international market by exporting 227 Te of HW in a decade's time by executing as many as 15 export orders. All consignment met stringent specifications of the users and followed all regulatory requirements. Superior quality of Indian product has earned due recognition for DAE in the international market.

In 2007, for the first time, HWB supplied high quality HW to M/s Spectra Gases, USA for non-nuclear applications. Subsequently HWB executed export to CIL, USA.

Recently, in 2021, HWB executed two export orders to S. Korea and Japan for non-nuclear applications. Also in this year HWB participated in an international bid for supply of HW to Argentina for nuclear applications. HWB is receiving various export inquiries from the countries like, US, Russia, Germany etc. for supply of high quality of Heavy Water which is indeed a matter of pride for the country achieving the goal towards “Make in India”.

Export consignment of Heavy Water

v. Present Scenario in Heavy Water Production

Environment and energy conservation are the two key issues for sustainable development of industrial growth and for corporate social responsibility.

Concentrated efforts were put to reduce the cost of production of Heavy Water to maximum possible extent. This was achieved through process intensification, re-optimization of operating parameters, energy audits, use of energy efficient equipment, integration of heat transfer loops etc. Thrust was given to increasing the throughput by system analysis and debottlenecking the process, pinch analysis for heat exchange networking, re-optimization of CPP heat cycle, evaluation of the hydrodynamics of the systems, waste heat recovery, performance evaluation of rotary equipment etc.

All the above concentrated efforts have resulted in a significant reduction of over 30% in specific energy consumption for all the plants taken together over last decade. This amounts to a cumulative saving of over few hundreds' crore. Milestones in energy efficiency have been reached and yet new targets are set every year with regards to energy efficiency.

Beginning with Nangal in1962, total eight HWPs were built in India to meet its requirement of INPP. The demand and supply did not always match. Initially, the supply lagged the demand, but during 1990s, it overtook and surpassed the demand.

The H_2S-H_2O exchange process-based plants, being independent ones, proved their worth. They account for the major production of heavy water today.

Over a period of time, Heavy Water production has been increasing and specific energy consumption improving continuously.

Heavy Water Board has been giving utmost importance to industrial, occupational & environmental safety, right from site selection to designing, construction, commissioning and during operation of plants. Various design safety features were incorporated in the plants. Those are closed drain and vent system, scramming and dumping system, toxic gas monitoring system and fire detection and protection system. Further, for the safe operation & maintenance of the plants, various safety systems were implemented. Those are plant audit, inspection and surveillance system, reporting and investigation system for reportable injuries, near-miss incidences and first aid injuries, safety work permit system, emergency preparedness and planning system and authorization system for operation & maintenance personnel. The functioning of these systems are audited and improved continually.

All the plants are certified for IS: 9001(QMS), IS: 14001(EMS) & OHSAS 18001/IS: 18001. As a result, HWB's safety record is the best among the Chemical Industries in India.

Heavy Water Plants consume large amount of power, water & chemicals. Therefore, conservation of natural resources, energy and environment protection were given due importance right from the beginning. Reduce, reuse & recycle of the natural resources is an ongoing process.

D. Non-Nuclear Applications of Heavy Water/Deuterium

Over a period of time it has been realized that other than application in nuclear reactor, deuterium has tremendous potential for applications in various high technological fields as predicted by Urey.

Deuterium isotope effect modifies the kinetics of chemical/bio-chemical reactions, which leads to many gainful applications in bio-science and advanced technologies. These applications are called in a broader term as 'Non-Nuclear Applications' (other than nuclear application of Heavy Water in pressurized Heavy Water reactors).

The applications include metabolism studies, NMR solvents, deuterated drugs/Active Pharmaceutical Ingredients (API's), optical fiber, semiconductors etc.

Recognizing the vast potential of Non-Nuclear Applications of Heavy Water and Deuterium, HWB had initiated various activities in this field since late 90s. A project was initiated by HWB in collaboration with Entero Virus Research Centre, Mumbai to validate the published data on thermostabilization of Oral Polio Vaccine (OPV) in heavy water medium. Though it was established that OPV in heavy water medium can retain its potency at much higher temperature compare to that in normal water medium, this benefit could not be potentially exploited for actual application due to other issues. However, that was not the end, as it triggered the beginning of our journey towards developmental work on non-nuclear applications of heavy water and deuterium.

Non-nuclear applications of Heavy Water picked up momentum in recent years as was clear from the increased number of inquiries received by HWB for supply of Heavy Water in bulk quantity to private industries for a wide range of applications viz. in NMR solvents, in medicinal chemistry, in optical fiber etc.

- **Development of deuterated compounds by HWB**

  HWB as a part of its diversification programme has taken up development of D-labeled compounds including NMR solvents. Presently all the compounds are being imported in the country. Heavy Water Plant (HWP), Baroda laboratory took up the activity of setting up the facility for in-house developments of methods for deuterium labeling of Hydrogen bearing compounds like $CDCl_3$, acetone-d6, acetonitrile-d3, DMSO-d6, benzene-d6, etc. under the DAE approved XII Plan R&D project of BARC. HWB successfully executed the project. Hands on experience in process selection, process optimization, quality control for development of deuterated compounds has been achieved through this project. Till now this facility is being utilized for synthesis of deuterated NMR solvents under applied R&D and products are being marketed through Board of Radiation &Isotope Technology (BRIT), DAE. An augmented facility for production of CDCl3, DMSO-d6, Acetone-d6 and Acetonitrile-d3 is being set up at HWP Baroda.

- **Collaborative agreement with Indian Private Parties**

  HWB has entered into collaborative agreement with two Indian Parties, M/s Clearsynth, Hyderabad and M/s SyNMR, Bangalore for development of deuterated NMR solvents, reagents, APIs and other value added products. Both the parties have made good progress in the intended work, using Heavy Water supplied by HWB.

- **Supply of Heavy Water for non-nuclear applications**

  HWB is promoting research and commercial activities by supplying Heavy Water within the country. Demand of Heavy Water for non-nuclear applications is consistently increasing and number of users in the country has also been on the rise.

- **Deuterium Depleted Water**

  Deuterium Depleted Water (DDW) is another field that is gaining prominence due to reported benefits for its application in therapeutic uses mainly in cancer treatment as adjuvant therapy.

  Preliminary results from a project with ACTREC, Mumbai were encouraging in regard of anticancer potential of DDW in specific cancer cell lines. A collaborative project for further systematic study in this line is being taken up with ACTREC.

  DDW with various deuterium content is available in international markets. HWB being the largest producer of Heavy Water has the capability of producing large quantities of deuterium depleted water and supply the same at various concentrations ranging between 30 ppm to 120 ppm for societal purpose.

E. Diversified activities of HWB

i) Production of Nuclear Grade Solvents for closed nuclear fuel cycle

Various Organo-phosphorous and Amide based nuclear grade solvents were identified as essential inputs to the front-end and back-end of nuclear fuel cycle for recovery and separation of Rare Earth & other valuable metals for fuel processing or reprocessing of spent fuel.

During the journey of last two decades, HWB in collaboration with BARC & IGCAR has developed industrial scale technologies for production of solvents viz. Tri butyl phosphate (TBP), Di-2 ethyl hexyl phosphoric Acid (D2EHPA), Tri octyl phosphine oxide (TOPO), Tri alkyl phosphine oxide (TAPO), Di nonyl phenyl phosphoric acid (DNPPA), N,N-di hexyl octanamide (DHOA), Tri iso-amyl phosphate (TiAP), 2-Ethylhexyl phosphonic acid mono-2-

ethylhexyl ester (PC88A) etc. 1,3-Dioctyloxycalix[4]arene-crown-6 (CC6) solvent also known as Calix Crown-6 has been identified as one of the potential candidate for selective separation of ^{137}Cs from high level waste of spent fuel. This solvent has been developed by NRG, BARC at lab scale. Scaling up for higher production was taken up at HWP, Talcher, and trial runs yielded few kg of CC6 which has been handed over to NRG, BARC.

ii) Boron Isotopic Enrichment and production of enriched boron compounds for second stage of Indian Nuclear Power Programme (INPP)

Prototype Fast Breeder Reactor (PFBR) being set-up at Kalpakkam as a part of IInd stage of NPP requires ^{10}B Enriched Boron Carbide for Control Safety Rod (CSR) and Diverse Safety Rod (DSR) sub-assemblies. HWB has successfully demonstrated & deployed the technology for production of ^{10}B Enriched Boron Carbide complying to CSR & DSR specs. Considering urgent need for supply to PFBR, HWB have installed enrichment facility at HWP-Talcher and Elemental Boron, B_4C conversion and pelletisation facilities at HWP-Manuguru. The initial requirement of enriched boron carbide has already been met successfully.

iii) Production of Nuclear Grade Sodium for second stage of INPP

HWB is entrusted for setting up of industrial scale Sodium Metal plant to meet sodium requirement of Second phase of INPP. Presently, there is no indigenous manufacturer of Nuclear Grade (NG) sodium in India. Hence, for meeting the demand of NG sodium for future FBRs and making FBR programme successful, self-reliant, it is necessary to have an indigenous source of sodium metal. A 2 kA test cell has been setup, commissioned & operated at HWP-Baroda. Based on operating experience and various modifications incorporated on 2 kA cell, 24 kA single cell design has been finalized and installed at HWP Baroda, which would serve as prototype cell in setting-up of multiple 24 kA cell for 600 MTPA NG sodium plant. While developing the prototype cell, HWP Baroda has installed a sodium purification unit based on technology provided by IGCAR. Subsequently, HWP Baroda produced 3 MT NG sodium metal and supplied to IGCAR.

Based on the operating experience in running the prototype unit and purification unit, further activities for setting up of 600 MTPA facility is being taken up by HWB.

iv) Production of ^{18}O enriched water

^{18}O enriched water, a specialty material finds wide spectrum of applications in the field of nuclear medicine and biomedical research. ^{18}O enriched water with >95 % IP (^{18}O) is required for carrying out PET scanning for detection and staging of cancer in patients.

HWB has adopted the Heavy Water distillation process (under vacuum) for enrichment of ^{18}O. Being first of its kind for HWB and DAE, a tedious technology development cycle from literature survey to the commercial production had to be followed.

Based on the optimizing studies carried out, a ten stage cascade was finalized to achieve reasonable inventory built-up time of around 4 years. The product of this cascade is $D_2{}^{18}O$, which needs to be split and recombined with pure Hydrogen at the back-end to give the desired product form $H_2{}^{18}O$.

Recently, during January-2022, 1st drop of ^{18}O enriched water has been produced at HWP Manuguru with isotopic purity > 95.5%.

v) Developmental activities

HWB has also taken up various developmental activities in collaboration with BARC viz. recovery of cobalt from secondary resources, recovery of Gallium from Aluminum industry, recovery of Helium from Fertilizer plants, development of novel contacting devices for liquid-liquid extraction.

F. Dream realized

Realization of dream of indigenous production of Heavy Water in India was possible due to sustained efforts of an array of leaders from Heavy Water family. Bhabha's vision on self-sufficiency in the production of Heavy Water and subsequent export could be translated to reality through the dedicated efforts and perseverance of our pioneers like Shri D.C Gami, S. Fareeduddin, P.G. Deshpande, K.S. Bhimbat, R.K. Bhargava, S. Sharma. A dream to Drum to Diversification---the successful journey of HWB is attributed to its dedicated team of staff who has put in untiring efforts in achieving the goal.

Moving from scarcity to surplus with respect to production of Heavy Water through sustained production with continual improvement, HWB has contributed in realizing the mission of 1st stage INPP. HWB has, over past few decades, mastered the highly complex and energy intensive technology of Heavy Water production through multiple processes including H_2S-H_2O and NH_3–H_2 isotopic exchange processes. Presently HWB is capable to design, construct and operate Heavy Water Plant on its own.

During last four decades of its journey in the field of Heavy Water, HWB also developed a large talent pool and expertise in various facets of chemical process plant right from concept to commissioning, including process and technology development, project implementation, etc.

HWB is demonstrating a strong presence in all the stages of India's Nuclear Power Programme. HWB is actively contributing to Nuclear Fuel Cycle by sustained supply of nuclear materials like Heavy Water for PHWRs, organo-phosphorus solvents for front and back-end of nuclear fuel cycle, ^{10}B enriched boron for FBR etc. HWB is also working on other areas of advanced technology for nuclear, societal and environmental applications. HWB is committed to take up more and more challenging assignments in the Indian Atomic Energy prograamme.

Applications of deuterium in non-nuclear field are now diversified at large. HWB is putting efforts to enter in to new horizons by taking up various research projects on developmental work on applications of deuterium in medicinal chemistry/biological field in collaboration with academics/research institutes/industries, utilizing the deuterium resources as well as knowledgebase available in the country.

Though the dream has come true and HWB has delivered, it is not the end of the journey. It continues and HWB remains active and vibrant as ever ready to face the future challenges.

As per data available, there are only few countries who are presently into manufacturing of deuterium oxide. Number of global sources for heavy water is reducing with heavy water plants in other countries near in entering shut down. There is a huge scope for HWB to play a key role in the global market of heavy water in near future by tapping the benefits of changing market trends for this market. HWB has demonstrated its core competence in field of heavy water production technology and is widening its horizon in line with the HWB's enlarged mandate of identification and promoting non-nuclear uses of heavy water/deuterium as deuterium labeled compounds for industrial and medical applications.

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