Nuclear Fuel Complex - Meeting the challenging requirements of Indian nuclear power programme over the last five decades

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Preamble

Nuclear Fuel Complex (NFC) has been established to shoulder important and critical responsibility of supplying nuclear fuel as well as core structural materials for Indian nuclear power programme. The historical evolution of NFC in terms of its nucleation, evolution and meeting the challenging demands of thermal reactors (PHWR and BWR) over the last five decades is highlighted. Its important contributions to fast breeder reactor (FBR) programme in terms of high temperature and high burn-up compatible advanced stainless steel structural materials are enumerated. It also plays a vital role in important national missions in terms of design, development and testing of special materials. NFC stands as a testimony to "Atmanirbhar Bharat" mission of the country in indigenous design and development of nuclear materials as well as special materials.

I) Birth of Nuclear Fuel Complex

Nuclear Fuel Complex (NFC), a major industrial arm of the DAE, was conceived in mid of 1960s by the father of Nuclear Power Programme Dr. Homi J Bhabha. It came into existence formally in 1971 at Hyderabad. NFC is engaged in manufacturing and supply of Fuel sub-assemblies and other reactor core structural components to India's Pressurized Heavy Water Reactors (PHWR), Boiling Water Reactors (BWR) as well as Fast Breeder Reactors (FBR).

The production of nuclear grade materials with stringent quality requirements involves a mastery of many diverse technologies in the fields of mechanical, chemical and metallurgical processes. With comprehensive nuclear fuel manufacturing cycle under its belt, NFC is the only organization in the world to have capabilities to process uranium and zirconium streams from ore to core, all under one roof.

II) Production and technological milestones

After conceptualization of NFC during 1960s, a pilot plant was established in 1961 to produce nuclear grade natural UO_2 powder and pellets. Further, the half core of first PHWR (RAPS-I) was fabricated at Atomic Fuel Division (AFD), Trombay. The rich experience gained during this time has enabled DAE to embark upon commercial production of nuclear fuel and thus, Nuclear Fuel Complex (NFC) had come into existence with a production capacity of 100 Te of PHWR fuel and 24 Te of BWR fuel in 1972 at Hyderabad. The first 19 element PHWR fuel bundle with wire wrapped spacers was produced in NFC on 8th June 1973 with the available indigenous technologies and assistance from Russia & Canada.

It is appropriate to recollect the past that it took almost 21 years for NFC to produce first 1 Lakh fuel bundles and next 4 lakh fuel bundles could be produced in next 20 years time. Thus it took 40 years to manufacture first 5 lakh fuel bundles. However, NFC is now able to manufacture one lakh bundles in a year. This has been possible only with the adaptation and implementation of innovative and break-through technologies into manufacturing, inspection & testing methodologies. Every production plant in NFC has progressively increased their plant capacities by incorporating the state-of-the-art automation into their process and quality control systems.

To sum up, the successful journey that NFC made during last 50 years of its existence towards technological excellence from technology denial regime can be described in decade wise as follows:

1970 - 1980: Acquiring knowledge and first milestone

- India forayed into the domain of PHWRs and NFC was established at Hyderabad with a capacity to manufacture 100 TPY of PHWR fuel.
- It was all new for scientists and engineers to produce uranium and zirconium on industrial scale.
- Acclimatization of the processes and machinery of U and Zr production technologies.
- First 19 element PHWR fuel bundle with wire wrapped spacers in 1973.

1980 - 1990: Understanding the existing processes and introducing new ones

- The equipment and processes were either replaced or modified to make them suitable to Indian raw materials.
- Indigenization of processes has helped in scaling up the manufacture of Nuclear Fuel to 180 TPY.
- Graphite coating of clad tubes.
- The processes still remained manual and laborious, where uranium is seen moving from one process step to next process step.

1990-2000: Developing applications and second milestone

- This extra demand for fuel, due to new plants at Kaiga and Kakrapara plants, had thrown a serious challenge due to huge gap between demand and supply.
- Processes were modified suitably and scaled-up equipment were procured, installed and commissioned successfully to accommodate the newer demands.
- Manufacturing of first one lakh fuel bundle was completed in 1994.

2000-2010: Decade of innovations

- During this decade, NFC had implemented many process innovations and indigenized process equipment across all operations.
- Manufacturing technology for extremely thin-walled tubing was established and seamless Calandria tubes were produced for two 540 MWe PHWRs at Tarapur.
- 37-element PHWR fuel bundle was produced for the first time.
- NFC concentrated on development of engineering industry for its futuristic innovative requirements with respect to various reactor components, accessories for fuel assemblies and advanced automatic equipment.

2010–Till Date: Decade of technological revolution and significant milestones

- NFC has significantly exceeded its designed capacities by implementing automation in fabrication and inspection.
- Technology was developed to manufacture U-bend Alloy 800 tubing in 30 m straight length for Steam Generators of 700 MWe PHWRs.
- Established new manufacturing processes for seamless tubes in circular, square, hexagonal cross sections, double clad tubes, multi-clad varieties for different types of power reactors
- Manufacturing of 300 MT of Nuclear Grade Zirconium sponge at Zirconium Complex, Pazhayakayal.
- Manufacturing of first one millionth PHWR fuel bundle in 2018.

The diversified production activities of NFC for nuclear and non-nuclear applications are summarized in Fig.1. The range and diversity of products include the structural materials for thermal and fast reactors as well as nuclear fuels for PHWR and BWR reactors. NFC also takes the production of advanced and sophisticated components required for space, defence and strategic sectors.

During its 50 years of journey, NFC has attained complete self-reliance in the manufacture and supply of fuel and core components for PHWRs and BWRs operating in the country. In this process, it has achieved the following important milestones during PHWR fuel bundle production and the cumulative PHWR fuel bundle production as shown in Fig.2.

Successive Chief Executives of NFC had taken many visionary steps and brought forth many innovations in the plant in terms of production, novel instrumentation and automation, safety, quality & inspection and human resource development. Various Chief Executives and their time period is given in the Table 1.

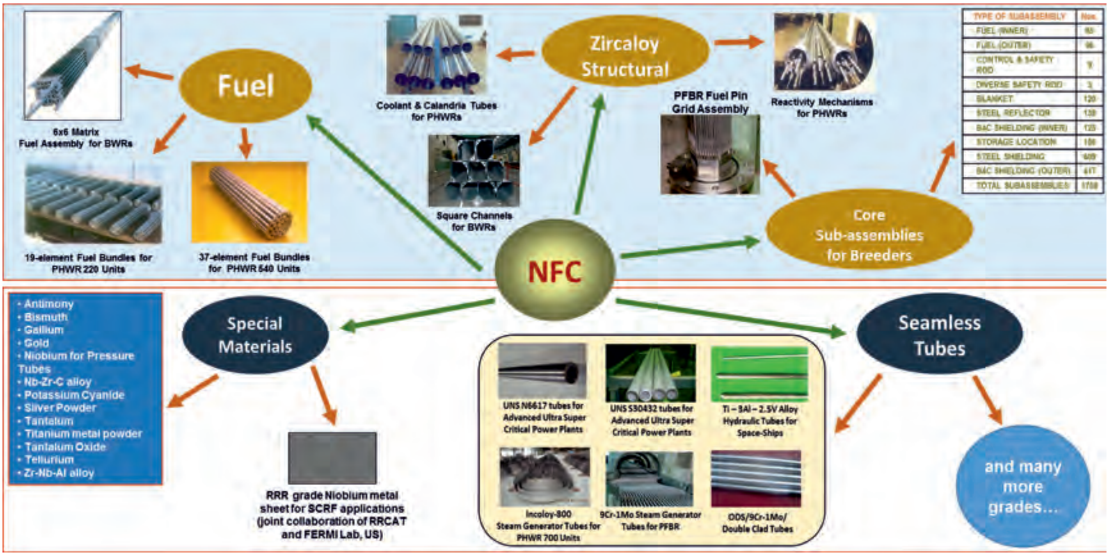

Fig.1: Diversified production activities of NFC

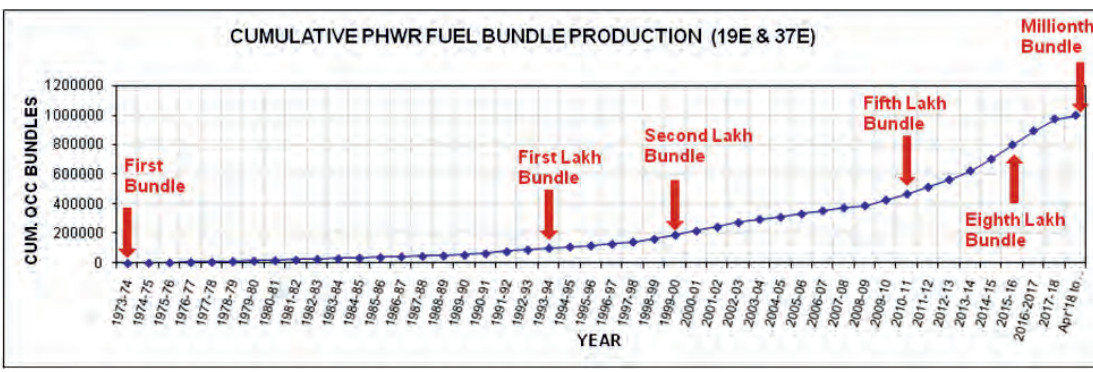

Fig. 2: Cumulative PHWR fuel bundle production over the years

Table1: Various Chief Executives of NFC and their leadership era

S. No.	Name	Time Period
1	Dr. N. Kondal Rao	1975 to 1984
2	Shri K. Balaramamoorthy	1984 to 1993
3	Shri K.K. Sinha	1994 to 1997
4	Dr. C. Ganguly	1998 to 2004
5	Dr. R. Kalidas	2004 to 2006
6	Shri R.N. Jayaraj	2006 to 2012
7	Dr. N. Saibaba	2012 to 2016
8	Shri G. Kalyanakrishnan	2016 to 2018
9	Dr. Dinesh Srivastava	2018 to Till date

III) Production activities in NFC

Nuclear grade natural Uranium Dioxide (UO_2) pellets are produced at NFC by converting variety of raw materials using a well-established conversion processes comprising of different stages like dissolution, solvent extraction, precipitation, calcination and reduction to get UO_2 powder. Subsequently, pellet fabrication is accomplished through granulation, pre-compaction and high temperature sintering of UO_2 powder. The resultant UO_2 pellets are then qualified for physical integrity and chemical purity for encapsulating them into zirconium alloy fuel tubes for fabricating the fuel sub-assemblies. The desired specifications are achieved by having a strict control on material manufacturing process. Control on manufacturing process can be achieved through monitoring the quality of materials taking part in the process and also with a strict vigil on process conditions. Chemical Quality Control (CQC) of raw materials, process intermediates and final products will ensure the desired quality of final products and thus, it becomes integral part of QA/QC program. As an independent department, Quality Assurance (QA) group ensures the quality at intermediate stages and final stage of production to ensure the compliance to the requirements of the customer. Safety and Environment Protection are also ensured with the designated departments during entire manufacturing process.

Besides this, NFC also manufactures different reactor components using special alloys including special steels for special application and also produces high purity materials of 5N & 6N purity for electronic & tool applications. Apart from principal customer NPCIL, the list includes DRDO, ISRO, HAL, BHAVINI, IGCAR, BARC, RRCAT etc.

Contributors to the success of NFC

NFC has been successful in meeting its challenging targets owning to its high quality production facilities as well as the technically strong and skilled manpower. They are engaged in manufacturing of nuclear fuel, in-core and out of core structural, special tubes and special materials backed up by a strong quality monitoring group to ensure the quality of the materials produced. Safety group is functioning to take of care of safety of all operations. The activities of individual production plants at NFC are described below:

1) *Nuclear fuel manufacturing plants*

Nuclear Fuel manufacturing is very critical and plays a vital role in nuclear fuel cycle. The stringent chemical, physical and metallurgical specifications of nuclear fuel need to be implemented into the nuclear fuel during its processing and manufacturing. The physical characteristics also need to be engineered based on the operation conditions of the nuclear fuels, which are quite harsh and also varying from reactor to reactor. The nuclear fuels during their operation are subjected to high temperature operating conditions, high neutron flux environment which leads to physical, chemical and metallurgical changes. Nuclear fuel is made for three types of nuclear power reactors, namely Pressurised Heavy Water Reactor (PHWR), Boiling Water Reactor (BWR) and Fast Breeder Reactor (FBR).

(a) PHWR Fuel Assemblies: Natural uranium dioxide (Natural UO_2) is the fuel for PHWRs and is obtained from different raw materials like Magnesium Di-Uranate (MDU), Sodium Di-Uranate (SDU) or Uranium Ore Concentrate (UOC). MDU/SDU concentrate is obtained from the indigenously milled uranium mines at Jaduguda, Jharkhand/Tummalapalli, Andhra Pradesh and supplied by Uranium Corporation of India Limited (UCIL) and UOC is imported from different countries. The processed UO_2 Powder is further converted into high-density cylindrical pellets by various operations like pre-compaction, final compaction and sintering at high temperature

(1700°C) in reducing atmosphere. The sintered UO_2 pellets are then centre-less ground to desired dimensions. The finished UO_2 pellets are encapsulated in thin walled Zircaloy tubes, both ends of which are sealed by resistance welding. Appendages such as spacers and bearing pads are resistance welded on these elements and 19 or 37 such elements of specified configuration assembled together by welding them on to end plates at either end to form 19-element fuel assembly designed for 220 MWe reactors and 37-element fuel assembly designed for 540 MWe and 700 MWe reactors. The three types of fuel sub-assemblies (bundles) fabricated in NFC are 19 Element bundle for 220MWe PHWRs, 37 Element bundle for 540/700 MWe PHWRs, 6x6 BWR bundle for 160MWe BWRs and these are shown in Fig. 3.

19 Element bundle for 220MWe PHWR | **37 Element bundle for 540/700 MWe PHWR** | **6x6 BWR bundle for 160MWe BWR**

Fig.3: Three types of fuel sub-assemblies (bundles) fabricated in NFC

(b) BWR Fuel Assemblies: Cylindrical UO_2 pellets of varying enrichments and chemical compositions imported from other countries are encapsulated in thin walled tubes of zirconium alloy, both ends of which are sealed by Tungsten Inert Gas (TIG) welding. Elements with varying compositions are placed in a specified configuration such as 6x6 array along with spacer grids, stainless steel tie plates, zirconium alloy spacers and flow nozzles to form 6x6 nuclear fuel assemblies for BWRs.

(c) Fast Breeder Reactor (FBR) Fuels: NFC is also responsible for fabrication of core subassemblies for Indian Fast Breeder Reactors deployed under 2nd stage of Indian Nuclear Power Program at Kalpakkam. The facility at NFC presently caters to the requirements of core subassemblies for two reactors namely 13MW(e) Fast Breeder Test Reactor (FBTR) and 500MW(e) Prototype Fast Breeder Reactor (PFBR). NFC fabricated all the core subassemblies such as fuel, blanket, nickel reflector, carrier and special assemblies for its initial core of FBTR in the beginning. Since then, it is also engaged in continuously supplying annual requirements of fuel and special subassemblies of FBTR. A typical FBTR fuel subassembly consists of 511 intricately machined components of 35 different types. The Core subassemblies are hexagonal in shape with very thin wall special grade stainless steel (SS) tubes (circular and hexagonal) and precision SS components. These were fabricated with in-house developed know-how and equipment/fixtures built with indigenous capabilities. Pelletisation of the thorium oxide (ThO_2) has been carried out for the first time on a large scale that involved considerable ingenuity and effort. NFC fabricated and supplied core subassemblies like Fuel, Blanket, Control & Safety Rod, Diverse Safety Rod, Reflector, Inner Boron Carbide Shielding, Diluent, Purger, Source and Instrumented Central Subassemblies for initial core of PFBR. A photograph of a typical Fuel Sub-assembly (FSA) of a fast breeder Reactor is shown in Fig.4.

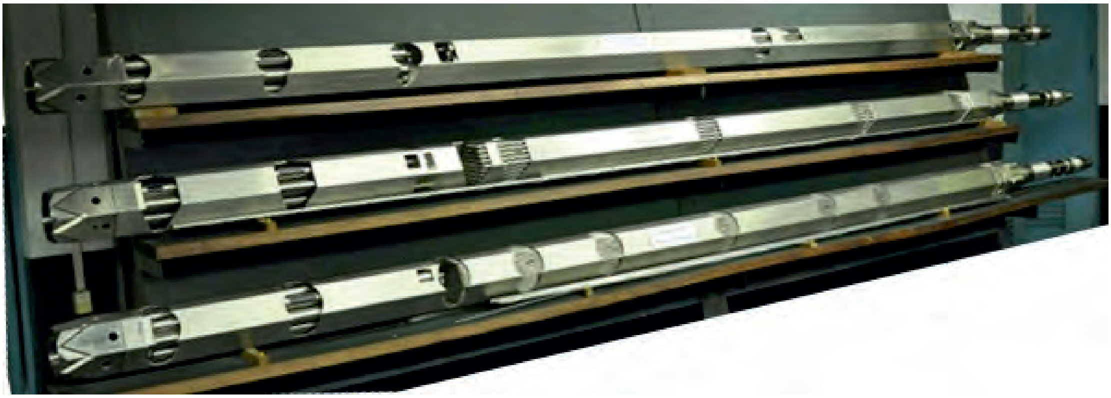

Fig. 4: FBR Fuel Sub-assemblies

2) *Reactor grade zirconium metal production plant*

Reactor Grade (RG) Zirconium metal (RG Zr metal) is produced by limiting critical impurity element Hafnium (Hf) making it suitable for nuclear applications. Zircon sand (zirconium silicate) is the raw material for the production of zirconium metal and it contains 67% zirconium with about 2% Hafnium. Hafnium being a neutron absorber element (due to its high neutron absorption cross section) making its removal as an essential step in the nuclear metallurgy of zirconium. The entire process of chemical separation, resulting in nuclear grade zirconium has been established at NFC so as to make required Zircaloy based structural materials for PHWR.

3) *Fuel Cladding and Assembly Components production Plants*

Chemically qualified zirconium sponge is converted into different types of zirconium alloys after addition of required quantity of alloying elements and melting. Zirconium metal and the alloying elements are compacted in hydraulic presses to obtain compacts / briquettes. These compacts are welded to each other by electron beam welding under vacuum to obtain a long cylindrical electrode. These electrodes are melted multiple times by consumable electrode in vacuum arc re-melting furnace in water cooled copper crucibles, with intermediate stage machining for obtaining final ingots. The typical composition of different Zircaloys manufactured at NFC is Table-2 as given below:

Table-2: Composition of various Zircaloys

Zirconium alloys type	Alloying elements (Weight %)				
	Sn	**Fe**	**Cr**	**Ni**	**Zr**
Zircaloy -2	1.5	0.12	0.1	0.05	Balance
Zircaloy -4	1.5	0.22	0.1	-	Balance

Zircaloy ingots are subjected to 1st stage of extrusion, machining and cutting. After making a hollow billet, it is subjected to beta-quenching, machining and 2^{nd} stage extrusion in order to obtain a hollow blank. This hollow blank is stress relieved in vacuum and passed on for multi-stage pilgering with intermediate vacuum annealing etc. Tube finishing operations like straightening, grinding, cutting, etc. are also performed to obtain the requisite stringent quality. For this purpose, NFC possesses state of the art fabrication facilities such as extrusion & piercing press, cold rolling mills, vacuum annealing furnaces, special surface finishing and further, heat treatment equipment are available to achieve the desired mechanical and metallurgical properties of cladding tubes.

4) *Nuclear Reactor Core Component Production Plants*

Seamless tubes of different sizes are being manufactured using alloys of zirconium, titanium and special grade stainless steels. Pressure Tubes (Zr-2.5wt% Nb alloy), Calandria Tubes (Zircaloy-4) and Garter Spring (Zr-2.5wt% Nb-0.5wt% Cu alloy) are the critical core structural of Pressurised Heavy Water Reactors (PHWRs). Square Channels (Zircaloy-4) are used in Boiling Water Reactor (BWRs) and Hardware like Hexcans (SS316/ D9 alloy) are used in Fast Breeder Reactors (FBR). Manufacturing process routes for these critical cores structural are successfully developed and continue to be supplied to all the PHWRs, BWRs and FBRs. Also, manufacturing process route for reactor control assemblies required for PHWRs are successfully developed and continue to be supplied to all the PHWRs. These assemblies are designed for reactor power monitoring, control mechanisms and shut down. These are made of zirconium alloys and require high precision, reliable components and high quality tubes before welding. The manufacturing processes use hot extrusion, forging, pilgering, drawing of various sizes of tubes and punching, machining of components. These assemblies use combination of electron beam welding, TIG welding and resistance welding and have stringent quality specifications for soundness of welds and accurate dimensional control. In addition, NFC has contributed in various developmental programs of the DAE such as Compact High Temperature Reactor, Upgraded APSARA Reactor through advanced machining and welding of exotic materials.

5) *Stainless Steel and Special Alloy Tubes production plants*

These are exclusive facilities for development & manufacturing the seamless tubes using various advanced grades of Stainless Steels & Special alloys, Nickel based super alloys, Iron based super alloy, Titanium alloys, Maraging steels for Nuclear, Space and Defence strategic applications. They house state of the art manufacturing facilities like Cold rolling mills (Pilger mills), Tube straightening mills of different capacities & sizes, Draw-bench, heat treatment facilities like Bright Annealing furnace, Vacuum Annealing furnace, Roller Hearth (LPG fired) Annealing furnace, Chemical operations like De-glassing, Pickling, Passivation, Alkaline degreasing, Solvent degreasing and Inspection facilities like Ultrasonic, Eddy Current & Hydrostatic Pressure Testing , etc. NFC has played a pivotal role in indigenous development & manufacturing of these products as import substitutes and is an excellent example for Make in India policy.

6) *Special Materials Plant*

Nuclear Fuel Complex is also the country's premier facility engaged in manufacture of variety of high purity materials (5N/6N) and they find numerous applications in Electronics, Defence, Nuclear Industries, Scientific & industrial research organizations, institutions of higher learning and even in general engineering industry.

High purity materials such as antimony, bismuth, cadmium, tellurium, tellurium, gallium, phosphorous oxy chloride, antimony trioxide, gold, gold potassium cyanide (GPC), silver are produced. In addition, tantalum pentoxide, tantalum metal and reactor grade niobium metal in the forms of rod, sheet and crucibles are also produced. The high purity materials are used in semiconductor technology for the synthesis of compound semiconductors, and as dopants, diffusants, solders, etc. Tantalum is used in variety of high temperature and corrosive atmosphere. Tool grade tantalum pentoxide finds its application in tool industry. Reactor grade niobium is used in nuclear industry for alloying of zirconium to produce special ZrNb alloys. NFC has produced Residual Resistance Ratio (RRR) grade niobium metal for use in superconductivity cavity (SCC) applications. Advanced alloys such as NbTi, NiTi, NbZrC have been developed by electron beam melting route.

The production of these materials involves a variety of highly sophisticated equipment, advanced techniques, clean working environment and specialized technical skills. The gamut of operations include hydrometallurgy, pyro-metallurgy, electrolytic processes, solvent extraction, special distillations, zone refining, Electron beam refining, etc. Rigorous quality control is exercised at all stages of production to achieve required high quality and reliability of the products. The availability of wealth of talent, advanced equipment and state-of-art of technology, backed up by excellent quality assurance processes ensure the quality of the products.

Further, NFC has transferred developed technologies to prospective entrepreneurs. These include technology for the production of Magnesium granules, Zirconium metal power, production of high purity materials such as Phosphorous Oxy Chloride, Indium, Sodium Iodide, Gallium, Gold, Silver, Capacitor grade tantalum powder and Tantalum anodes etc., A new production plant is being set-up in collaboration with ISRO for the production of niobium for exclusive usage in Indian Space programme.

7) *Quality Assurance Group*

Quality is important in any field of human endeavour, more so in a critical, high-tech area such as nuclear power plants, where the costs of failure are extremely high with respect to material loss and also from the societal angle. The demands thus made on the Quality Assurance (QA) programs in DAE in general and NFC in particular, are altogether at different level compared to those in other industries. NFC is unique in its integrated approach to manufacture a variety of finished products from ore to core through employing enormous amount of Inspection, QA and Non-Destructive Evaluation (NDE) on an industrial scale. Because of these demands, NDE in NFC has, through years of experience, attained a high level of maturity. NFC is striving to achieve six sigma strategy as a part of continual improvement in its operations, products and services through technological excellence and well-integrated QA program. The exacting performance required by the nuclear fuel and hardware in the power reactor demands fulfilling stringent quality requirements of each product specifications.

NFC adopts well-structured quality assurance program. Sophisticated non-destructive evaluation facilities were developed and these techniques include ultrasonic test, eddy current test, X-ray radiography, dye-penetrate test, mass spectrometric leak detection and automated machine vision systems. Precision dimensional measurement systems and automatic physical measurements facilities caters the in-house needs for measurement and qualification of products.

An array of analytical techniques like Inductively Coupled Plasma Atomic Emission Spectrometry, Atomic Absorption Spectrometry, X-ray Fluorescence Spectrometry, Mass Spectrometry, Gas and Ion Chromatography, Laser Photometry are employed for analysis of raw materials, intermediates and final products. A number of online measurement and control equipments have been deployed all along the processes and production lines. The Advanced Material Characterization Lab is equipped with several sophisticated characterization instruments viz. TEM, SEM-EBSD, XRD, Dilatometer, X-ray residual stress analyzer for studying metallurgical characteristics like microstructure, texture, dislocation density, re-crystallization behavior, crystallography, nano-feature characterization, residual stress analysis etc. These facilities help in developing a variety of products and advanced alloys. NFC has over the past five decades earned a justifiable respectable place in the DAE as a reputed, reliable, quality conscious supplier of critical inputs to the nuclear power program in India.

8) *Safety Engineering Division (SED)*

NFC gives utmost importance to the safety of workers, environmental protection and prevention of accidents / incidents at field level. It is regulated by Atomic Energy Regulatory Board (AERB). For taking care of overall safety aspects, to achieve the objectives of safety and co-ordinate with various plants, Safety Engineering Division (SED) is formed in the initial years of NFC. SED coordinates with AERB on regular basis for the implementation of Factories Act, 1948 and Atomic Energy Factories Rules, 1996 and other statutes.

9) *Environment Protection*

While fulfilling the mandate of supplying the nuclear fuels and nuclear reactor components to Nuclear Power Program and to support strategic programmes of India, NFC gives utmost importance to protect environment by way of proper handling and disposal of by-products and effluents. A dedicated Effluent Management section comprising of expert chemical engineers is working towards this goal. The section is responsible for safe & prompt disposal of various process effluents generated during various activities at NFC to firms/establishments authorized by Telangana State Pollution Control Board (TSPCB).

IV) New Projects

(a) Zirconium Complex, Tamil Nadu (A Unit of NFC, Hyderabad):

In order to meet the additional requirements of production of zirconium metal, Zirconium Complex (ZC) was conceived in 2001 as a green-field project at Pazhayakayal, Tuticorin, Tamil Nadu. ZC was commissioned in November 2009 to produce zirconium oxide and zirconium sponge to meet the enhanced demand. During the last 13 years, the production capacity of the Plant has been gradually increased and the rated capacity was achieved in FY 2014–15.

ZC has future Plans of setting up of Magnesium Recycling Technology Development & Demonstration Facility and capacity augmentation of zirconium sponge production to meet the future demands commensurate with the nuclear power programme. The ground work in this direction has been already initiated by NFC. Further to this, a plan of action has been worked-out to enhance Zr production to 1300 TPY through capacity expansion at Zirconium Complex, Pazhayakayal in two phases.

(b) NFC-Kota, Rawatbhata, Rajasthan

A new fuel fabrication facility is being set up (NFC-Kota) at Rawatbhata near Kota, Rajasthan. This green field project is established with a plant capacity of 500 TPY PHWR fuel fabrication and 65 TPY fuel cladding fabrication. The capacity of fuel cladding fabrication will be further augmented by 100 TPY. NFC-K project envisaged to establish 37 element fuel bundle manufacturing facility to cater to fuel requirement of up-coming 700 MWe PHWRs. The project is in advanced stage of completion and is expected to take-up the production shortly.

(c) Developments in Zirconium Sponge Metal Production

Technology Demonstration Unit has been successfully commissioned at ZC, Pazhayakayal, Tuticorin, Tamil Nadu for the production of 1500 Kg batch against regular batch size of 950 Kg for the first time. Several batches are produced through this process. The efforts have been made to reduce the production cycle time and to meet the additional requirements of sponge metal. The chemical analysis of the 1500 Kg Zr sponge batches produced is meeting the technical specification. Higher productivity, improved purity, energy savings and improved recovery by 2% are the advantages. Fig. 5 shows the production facility with a picture of typical batch produced.

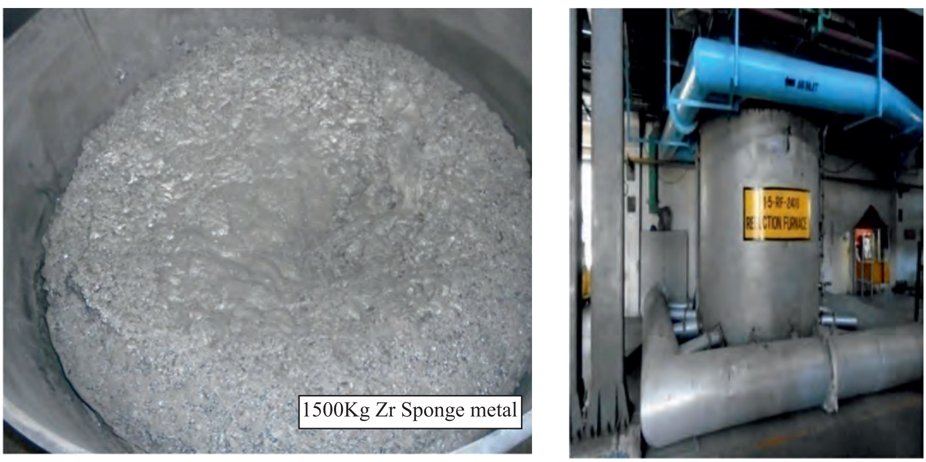

Fig. 5: 1500 Kg Zr-metal produced and Facility for its production

V) "Atmanirbharta"- a Make-in-India Initiative

(1) Indigenous EB Melting Furnace

In view of restricted technology, a successful effort was made in NFC to build indigenous electron beam melting furnace. The indigenously built EB Melting Furnace is used in melting and purification of refractory & reactive metals and alloys for strategic applications in Nuclear, Space, Defence fields. The efforts have resulted in huge revenue savings for the department and eliminated the dependency on external agencies for maintenance of the furnace. The EB Furnace was built for the first time in India using indigenously available resources and in the process India has become 4th country in the world to have such a facility. The facility was inaugurated by the President of India in May 2018 (Fig. 6) and since then being used for different the purpose.

Fig. 6: Indigenously built EB Melting Furnace and inauguration by H.E. Shri Ram Nath Kovind President of India in May 2018

(2) Manufacturing of Special Tubes

Several special grade steel tubes have been manufactured for special & strategic applications for first time in India as import substitutes. These include Incoloy-800 U bend SG tubes, Zr-1% Nb tubes, Titan-24/11 tubes, SuperNi 42, Inconel 690/600, Alloy 617 etc.

(3) Steam Generator Tubes for PHWR

NFC successfully manufactured Incoloy-800 U bend SG tubes first time in India. The production of 30 meter long Incoloy-800 U bend tubes is a technological challenge and NFC could do it successfully and delivered 8 sets for RAPS 7 & 8, KAPS 3 & 4 reactors. In view of very high demand, a dedicated facility has been established to double the production capacity to 6 sets per year. It generates significant revenue to NFC. It has opened an opportunity to NFC to become potential supplier of U bend SG tubes in International market. A typical picture of these tubes is shown in Fig.7.

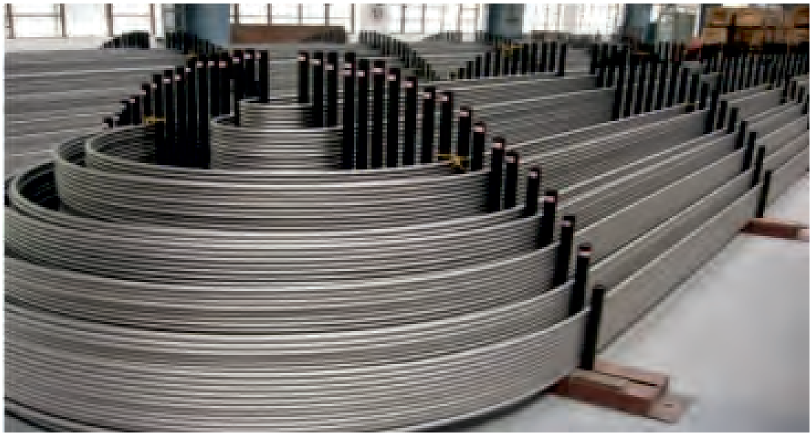

Fig.7: Incoloy-800 U bend SG tubes

(4) Titanium Tubes Manufacturing: Zirconium and titanium have similar metallurgical characteristics and processing routes (Extrusion, Pilgering , Heat Treatment, etc.). NFC with its vast experience of manufacturing Zircaloy tubes is well equipped to take up bulk manufacturing Ti-alloy tubes as import substitutes. Over the years, various Titanium alloy products like Titan-24 Tubes for strategic nuclear application, Ti-half alloy Truss rod Tubes for PSLV & GSLV, Ti half alloy Hydraulic Tubing for Light Combat Aircraft (LCA) have been developed. It is planned to augment capacity through an exclusive facility.

(5) SuperNi-42 Tubes: These tubes are of small diameter, extremely thin wall and have stringent specifications with respect to dimensional tolerances and metallurgical properties, as shown in Fig. 8. After initial trials for indigenous development in collaboration with BARC Mumbai, the manufacturing route was established for bulk production. The process consists of production through 10 stages of thermo mechanical processing followed by final finishing operations & stringent quality checks of mechanical testing, ultrasonic testing, dimensional & visual inspection.

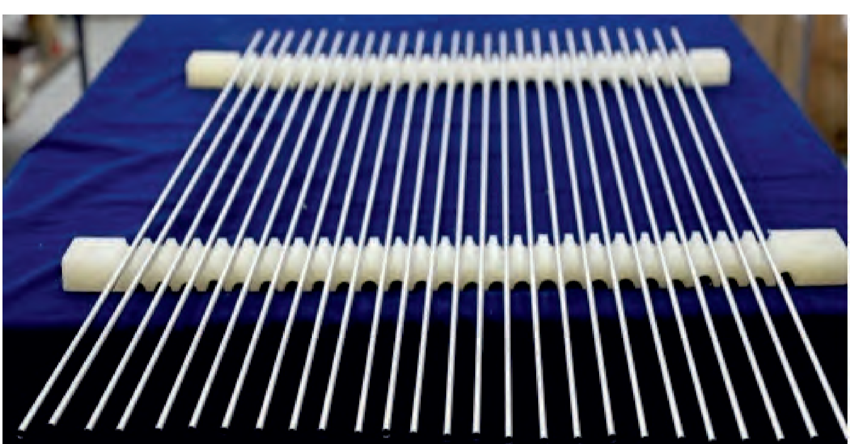

Fig.8: Typical picture of SuperNi 42 Tubes

(6) Other developmental works carried:

With well structured and established manufacturing process under its belt, NFC continuously made technological improvements to refine the processes. Some of them are as follows,

- NFC demonstrated with the production of 1500 MTe of natural uranium fuel, world's highest ever production.
- Manufactures and supplies 19/37 element Natural Uranium Fuel bundles for all the PHWRs and Enriched Uranium Fuel Assemblies of 6x6 types to BWRs. For the first time, 37 element fuel bundles with modified bearing pad design was made for the initial core requirement of India's first 700MWe PHWR at KAPS-3.
- In house development of Auto Ring gauging for PHWR fuel bundles, a mandatory requirement prior to loading of bundles in to reactor core.
- Development of automated vision based inspection system for surface examination and dimensional measurement of fuel bundle appendages viz. Bearing and Spacer pads to increase through-put with reliability.
- Development of High corrosion resistant SS - 304L pipes for Fast Reactor Fuel Cycle Facility(FRFCF).
- Development and manufacturing of D9 Fuel Clad Tubes and Pure Nickel Tubes for Prototype Fast Breeder Reactor (PFBR).
- Development of Alloy 617 tubes for Advance Ultra Super Critical (AUSC) power plant.
- Development and supply of Zr-1%Nb alloy tubes for strategic applications.
- Development and manufacturing of RRR Grade Niobium sheets for fabrication of Superconducting cavities.

Concluding remarks

NFC always sets a new benchmark in Never Fails in its Commitments attitude and continues to play a significant role in all NPCIL's ambitious future expansion programs, as well as its contributions to FBR programme and delivering the requirements of other departments like DRDO, ISRO as well. NFC has immensely benefitted from its synergistic interactions with BARC, NPCIL, IGCAR, BHAVINI, MIDHANI and many other national institutes in meeting its challenging goals in the service of the nation.