NUCLEAR FUEL FABRICATION - DEVELOPING INDIGENOUS CAPABILITY

U.C. GUPTA, R.N. JAYARAJ, MEENA, R., V.S. SASTRY,
C. RADHAKRISHNA, S.M. RAO, K.K. SINHA

Nuclear Fuel Complex
Department of Atomic Energy, India

ABSTRACT

Nuclear Fuel Complex (NFC), established in early 70's for production of fuel for PHWRs and BWRs in India, has made several improvements in different areas of fuel manufacturing. Starting with wire-wrap type of fuel bundles, NFC had switched over to split spacer type fuel bundle production in mid 80's. On the upstream side slurry extraction was introduced to prepare the pure uranyl nitrate solution directly from the MDU cake. Applying a thin layer of graphite to the inside of the tube was another modification. The Complex has developed cost effective and innovative techniques for these processes, especially for resistance welding of appendages on the fuel elements which has been a unique feature of the Indian PHWR fuel assemblies.

Initially, the fuel fabrication plants were set-up with imported process equipment for most of the pelletisation and assembly operations. Gradually with design and development of indigenous equipment both for production and quality control, NFC has demonstrated total self-reliance in fuel production by getting these special purpose machines manufactured indigenously. With the expertise gained in different areas of process development and equipment manufacturing, today NFC is in a position to offer know-how and process equipment at very attractive prices.

The paper discusses some of the new processes that are developed/introduced in this field and describes different features of a few PLC based automatic equipment developed. Salient features of innovative techniques being adopted in the area of UO_2 powder production are also briefly indicated.

1.0. INTRODUCTION:

Nuclear Fuel Complex was established in early 70's as an integrated facility to cater to the requirements of nuclear fuel for Indian nuclear power reactors. During the past 25 years, the Complex has been engaged in the production of fuel bundles and zircaloy structurals and their supply to reactor sites. Apart from developing innovative processes, design and fabrication of some special equipment was also undertaken by the engineers of NFC for manufacture of the fuel and related components.

The following sections of the paper highlight these aspects with reference to development of process technologies, equipment manufacture and future plans.

2.0. PROCESS DEVELOPMENT

2.1. UO_2 Powder Production:

A number of investigative studies were carried out at the powder production plant which led to the following major process changes in the plant:

To obtain nuclear grade UO_2 powder, the plant was employing pulsed column solvent extraction system for purification which was suitable for filtered solution resulting in considerable amount of uranium bearing silicious cake. Uranium recovery from this cake required repeated filtration. A slurry extraction system was therefore designed and incorporated in place of pulsed columns. For solvent extraction, crude solution is taken directly in slurry extractor instead of leached and filtered solution as is the case in pulsed perforated columns. The present processing of slurry extraction offers several advantages like elimination of cumbersome filtration operation, reduction in consumables & energy, ease of operation and lower maintenance. Similarly for stripping operation, pulsed column has been replaced with multi-stage mixer settler. In view of the satisfactory achievement with respect to the purity of the uranium solution, the scrubbing operation has been totally eliminated.

For better process control and output, tunnel type furnaces were replaced with high capacity rotary furnaces for calcination, reduction and stabilization. These equipment have moving beds which keep the charge agitated causing better heat transfer thus rendering more uniform product. The off gases from the rotary furnaces are let out through electrostatic precipitator.

In addition to the above process changes, the plant has introduced adequate instrumentation to closely control the process parameters at different stages which has resulted in eliminating hard particles in the powder and thereby avoiding milling and blending operations.

2.2. Fuel Assembly:

To keep in tune with the requirements of nuclear power stations and the changes taking place the world over, several process improvements were incorporated in Fuel Assembly plant . Note-worthy among them are -- switching over from wire-wrap design to split spacer design and introduction of graphite coated fuel tubes.

Towards the split spacer fuel manufacturing, extensive studies were carried out to select and standardize suitable processes for attachment of appendages onto the fuel sheath. In view of the requirement to attach large number of spacer / bearing pads, it was essential to select a joining process that is simple, rapid, cost-effective and yet meet stringent nuclear standards. Beryllium brazing technique, employed by other Candu fuel manufacturers in the world, was not chosen owing to its hazardous nature, high equipment cost and possible in-reactor problems associated with brazed joints (1,2).

Resistance welding process for attachment of appendages was opted for this purpose, which is the unique feature of Indian PHWR fuel bundles. The standardization of the process included design & fabrication methods of specially coined components; design and manufacture of special purpose equipment; standardization of process parameters and testing & qualification procedures. Since 1986 NFC has been continuously manufacturing split-spacer fuel bundles through resistance welding route. All the bundles have performed well in the reactors and till date no fuel failure is attributed to resistance welded appendage joints.

In order to reduce the chances of pellet clad interaction there was a need for introducing graphite coating on the inside surface of the fuel tubes. After carrying out considerable developmental work, the production process for graphite coating by employing simple gravity-flow technique was standardized. To ensure required adherence of the coating, vacuum baking is done for which the process parameters were optimized.

3.0. EQUIPMENT DEVELOPMENT:

The decision of Department of Atomic Energy, India, to install more nuclear power reactors of PHWR type laid greater emphasis on augmenting the fuel fabrication facilities at NFC. This in turn has posed the challenge to indigenously design and manufacture the required machinery for critical operations as it became known that India could not import these equipment easily. Also, certain processes unique to Indian PHWR fuel like resistance welding of spacer and bearing pads, necessitated building of equipment entirely on our own. Bestowed with vast shop-floor experience gained over the years, NFC successfully met the challenge of designing and fabricating the sophisticated highly productive equipment, both in-house and with the participation of Indian industries.

3.1. Equipment for UO_2 Powder Production:

All the process equipment required for UO_2 powder production were designed and fabricated indigenously by incorporating the necessary technical modifications to suit the process developments mentioned at para 2.1. Some of the critical equipment manufactured and employed for regular production are:

* Uranium Slurry Extraction and Purification System.
* Batch type Equilibrium Precipitation Units.
* Turbo Drier with 'Stirred-bed' concept.
* Rotary furnaces for Calcination/Reduction/Stabilization.

These equipment are operated through a dedicated microprocessor controller specially designed and built for the purpose.

3.2. Equipment for Pelletisation:

An integrated pre-compaction - granulation - vibro-sieving equipment consisting of pneumatic transfer arrangement for transferring virgin powder to the press is built. The combined system offers good quality granules such that high-integrity green compacts at final compaction stage can be obtained.

Large capacity sintering furnaces with several heating zones are built indigenously. The important features of these furnaces are --

* Individual heating zone controls to suitably adjust the temperature profiles depending on powder characteristics.
* Microprocessor controlled totally automatic charging /discharging of boats.

A general view of the furnace is shown in Fig - 1.

3.3. Equipment for Assembly Operations:

End Cap Welding Machine: One of the major import-substitute equipment successfully manufactured and operated is for -- "end closure welding", the most critical operation in fuel manufacture. The expertise gained over the years in understanding of the process has helped in incorporating sensitive systems in the machine. Some special features of the equipment are --

* Automatic feeding of zircaloy tubes and end-caps to the welding station via linear conveyor and bowl feeder/magazine respectively.
* Twin welding head arrangement to carry out welding on both ends of the tube simultaneously.
* Programmable weld controllers with on-line feedback and correction facilities.
* Data logging for important weld parameters.
* Positive arrangements for filling helium gas to desired pressure.

One such indigenously developed end-cap welding machine is shown in Fig - 2.

Spacer Pad Welding Machine: The first set of equipment to be developed right from the conceptual stage are the spacer-pad welding, bearing-pad welding and weld strength testing machines. Several concepts for feeding the spacers, precision indexing methods and welding parameters were tried and perfected. All the machine operations have been automated by utilizing micro-processor based control systems. Fig - 3 is a photograph of the spacer welding machine. The special features of the machine are --

* The template and feeding unit for positioning spacer pads on the fuel element is made up of metallic parts for reducing wear.

* Simultaneous welding of projections of the spacer pads in a transparent shroud which permits operator's view of welding.
* Specially designed pneumatic chuck for rotating the fuel element by a precise amount, to index it for welding of spacers at different angles.

Bearing Pad Welding Machine: The bearing-pad welding equipment has been developed to give high rate of production while maintaining consistently high quality of welds. A general view of one of the machine is shown in Fig - 4. These equipment have the following special features --

* Simultaneous welding at all the required number of projections on the three bearing pads.
* The template and feeding units for positioning three bearing pads on the fuel element are made up of metallic parts for avoiding wear.
* Direct-energy, AC synchronous type indigenously available welding power source
* Microcomputer controller developed in-house at NFC for automating the machine operations.

Weld Strength Testing Machine: These equipment are meant for determining the shear strength of individual welds of spacers and bearing pads of fuel elements by the destructive method. Fig - 5 depicts a view of the full-fledged testing machine. They have the following special features --

* Electro-pneumatically actuated element clamping and tool actuation.
* Built-in force transducer for dynamic strength measurement.
* Easy change-over between spacer pad testing and bearing pad testing.
* Automated machine operation.
* Computerized data logging and statistical analysis system.

Graphite Coating and Baking Equipment: This set of equipment is successfully designed in-house. Fig - 6 shows the graphite coating machine while Fig - 7 is a view of the baking unit. Some important features of the graphite coating and baking equipment are --

* Batch coating of 20 tubes at a time with ease of working.
* Batch size of 3,500 tubes for baking.
* Electronically controlled automatic operation.
* Facilities in the equipment to consistently maintain high degree of cleanliness.
* Adequate safety interlocks.

End Plate Welding Machine: Another important area of indigenization is for assembling and welding of end-plates to the cluster of fuel elements. The equipment is robust in construction and as shown in Fig - 8 has the following important arrangements:

* Auto indexing of fuel element cluster and end-plate.
* Automatic reversing of fuel bundle for welding second end.

* Sophisticated instrumentation for weld parameter monitoring and data logging.
* The same machine can take up welding of 19-element and 37-element fuel bundles.

3.4. Equipment Performance:

The equipment that were built in-house at NFC and those that were developed in collaboration with other Indian manufacturers are performing well. They have proved to demand less maintenance . The availability figures of some important equipment during the previous year are depicted in Fig - 9. As can be seen from the figure, the consistently high availability indicates the reliable performance and robust design of the equipment.

3.5. Cost-effectiveness of the Equipment:

A comparison of the cost of typical equipment when imported and when developed indigenously is indicated in the set of bar-charts shown in Fig - 10. The successful development of many special purpose equipment for nuclear fuel fabrication had resulted in considerable reduction in capital investment and running costs for our new plants.

4.0. CONCLUSIONS:

In order to meet the increased fuel demand in India, Nuclear Fuel Complex has embarked on expansion programmes, while simultaneously aiming its efforts towards upgrading the production processes and in developing capability for equipment building. The concerted efforts put in have yielded fruits in developing innovative processes and in manufacturing of all the equipment required for fuel production indigenously. Backed by 25 years of experience in PHWR fuel manufacturing, today NFC is in a position to offer process know-how and can set up fuel fabrication facilities on turn-key basis at competetive prices.

5.0. ACKNOWLEDGMENTS:

The authors are thankful to Department of Atomic Energy, India for giving opportunity and permission to present this paper.

6.0. REFERENCES:

1. FLOYD, M.R. et al, "Behavior of Bruce NGS-A Fuel Irradiated to a Burnup of 500 MWh/kgU", Third International Conference on Candu Fuel, 1992, October 4-8, Chalk River, Canada.

2. TEED, D.E. et al, "Structure of Candu Fuel Bundle", CNS, International Symposium on "The Complete Nuclear Fuel Cycle", Saskatoon, September, 1988.

FIG - 1 : SINTERING FURNACE

FIG - 2 : END-CAP WELDING MACHINE

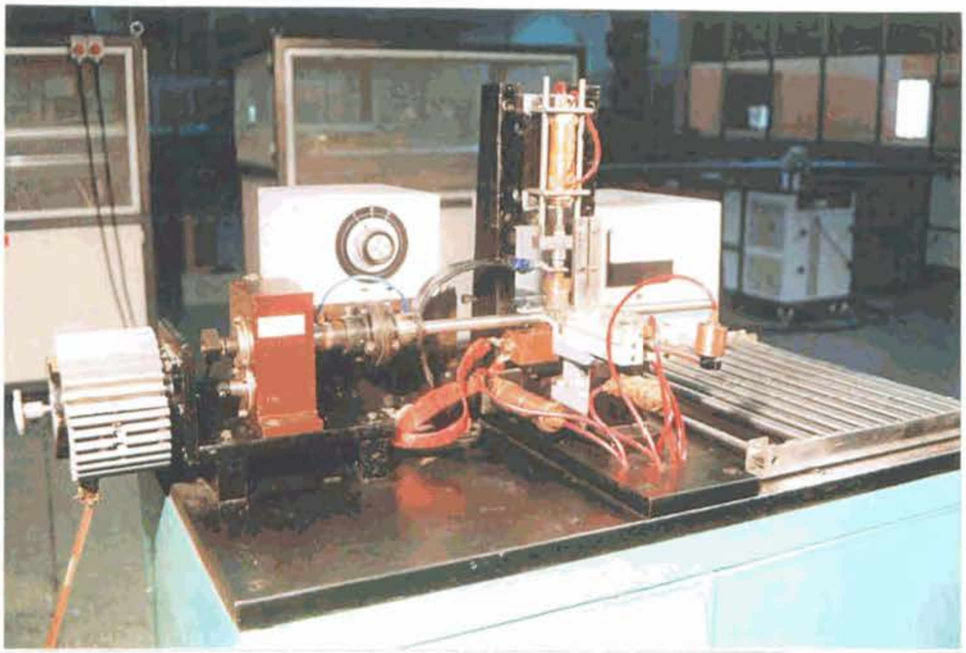

FIG - 3: SPACER PAD WELDING MACHINE

FIG - 4 : BEARING PAD WELDING MACHINE

FIG - 5 : WELD STRENGTH TESTING MACHINE

FIG - 6 : GRAPHITE COATING MACHINE.

FIG - 7 : VACUUM BAKING OVEN

FIG - 8 : END PLATE WELDING MACHINE.

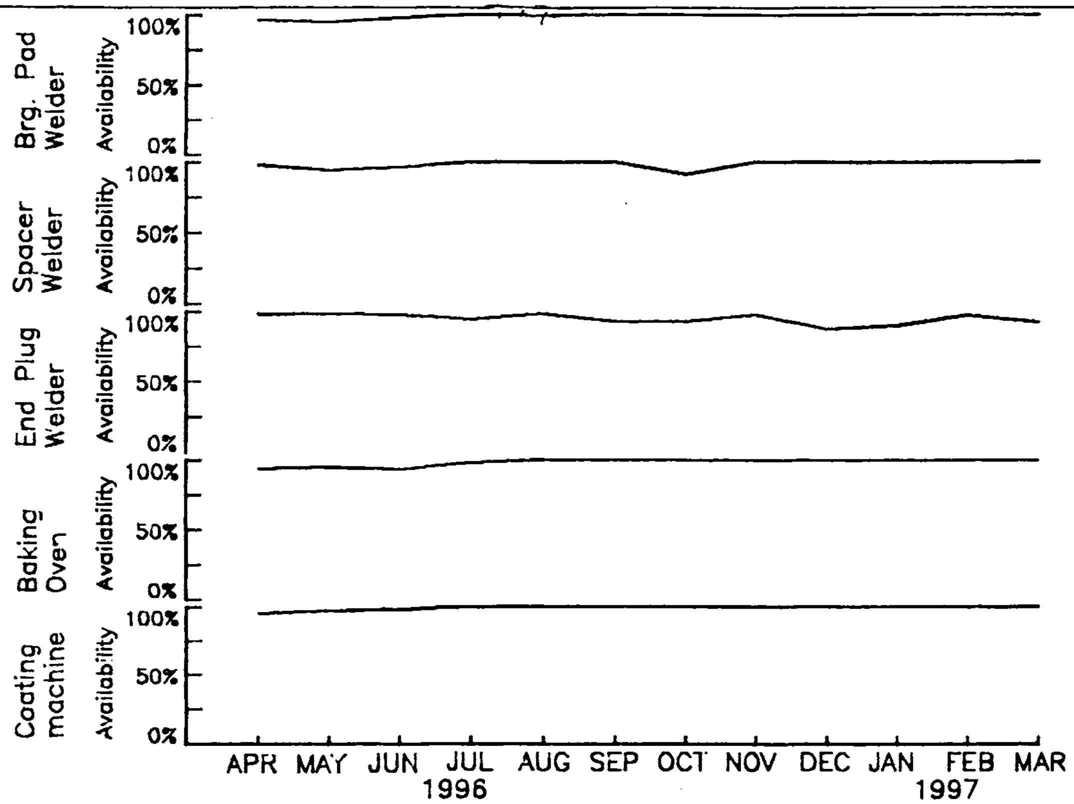

FIG – 9 : MACHINE AVAILABILITY FIGURES

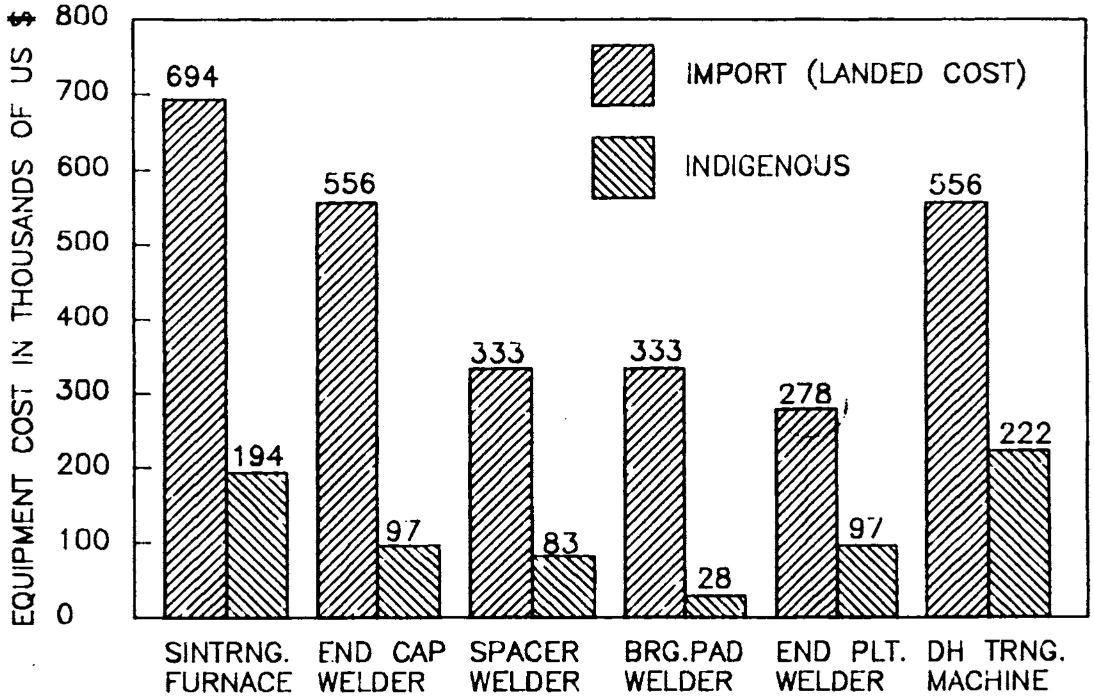

FIG – 10 : COMPARISON OF COST OF EQUIPMENT