RECENT ADVANCES IN FUEL FABRICATION TECHNIQUES AND

PROSPECTS FOR THE NINETIES

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ABSTRACT

Advanced Nuclear Fuels Corporation's* approach and experience with the application of a flexible, just-in-time manufacturing philosophy to the production of customized nuclear fuel is described. Automation approaches to improve productivity are described. The transfer of technology across product lines is discussed as well as the challenges presented by a multiple product fabrication facility which produces a wide variety of BWR and PWR designs. This paper also describes the method of managing vendor quality control programs in support of standardization and clarity of documentation. Process simplification and the ensuing experience are discussed. Prospects for fabrication process advancements in the nineties are given with emphasis on the benefits of dry conversion of UF_6 to UO_2 powder, and increased use of automated and computerized inspection techniques.

INTRODUCTION

Advanced Nuclear Fuels Corporation (ANF) is a wholly-owned affiliate of Siemens Capital Corporation. ANF has now completed 16 years of services to utilities with nuclear power plants in the USA, Europe, and Asia. The Company started with experienced individuals, and without takeover of an existing organization built up an organization with about 1,000 employees to supply fabricated fuel for BWRs and PWRs. ANF's emphasis on quality and technical innovations, which offer substantial value to utilities, has led to ANF's fuel being utilized in 41 reactors, including 21 PWRs and 20 BWRs. On the basis of firm business in hand, the number of reactors having operated with ANF fuel is expected to rise to over 45 within the next few years.

NUCLEAR FUEL FABRICATION

ANF operates a fully integrated fuel fabrication plant in Richland, Washington, in the northwestern USA, and a fuel rod fabrication and assembly facility in the Federal Republic of Germany.

The Richland plant is unique among fuel fabrication facilities in the United States in that, from inception, it has produced both BWR and PWR fuel. This has led to the fabrication of over 20 distinct fuel designs, ranging from the earlier 6x6 BWR assemblies to the latest 17x17 PWR assemblies with optimized high water fraction designs.

U. S. OPERATIONS

At the U.S. Plant the production process starts with conversion of enriched UF_6 to UO_2 powder and includes pelletizing, rod loading and assembly. An extensive inspection and quality control program is in place which assures conformance with extremely tight ANF tolerances and with a highly demanding, NRC-monitored, quality assurance program. The fabrication facility in Richland is capable of producing over 700 metric tons uranium per year. The fabrication plant is sufficiently flexible to allow fabrication of BWR and PWR assemblies in a wide range of configurations in any sequence desired, and includes gadolinia burnable poison manufacturing facilities, supporting analytical labs, and computer assisted manufacturing control activities. Engineering offices and R&D facilities are located at the same site, allowing close communication and integration with manufacturing activities. As of September 1987, the Richland Plant will have fabricated 1,500,000 fuel rods and over 11,500 fuel assemblies.

EUROPEAN OPERATIONS

The ANF business activities in Europe are coordinated through Advanced Nuclear Fuels International, Inc. (ANFI), with offices in Brussels, Belgium. Advanced Nuclear Fuels GmbH (ANFGmbH), a wholly-owned subsidiary of Advanced Nuclear Fuels Corporation, operates a nuclear fuel fabrication plant in Lingen, the Federal Republic of Germany. Since its startup in 1979, this facility has produced about 500,000 fuel rods fab-

*Previously known as Exxon Nuclear Company, Inc.

ricated into about 3,000 fuel assemblies utilized in 12 European nuclear power plants. This facility, with a current capacity of approximately 300 metric tons uranium per year, implements and uses the latest fabrication and quality control techniques developed and utilized in the U.S. facility.

FLEXIBILITY IN MANUFACTURING

The advantages of fuel production in a multi-product, flexible facility include the cross-transfer of technologies and ideas, which result from rotation of BWR and PWR design and production personnel. Examples are: adaptation of the axial blanket design from BWR to PWR fuel, and the introduction of gadolinia burnable poison in PWRs, designs for removable upper tie plates, and use of bimetallic spacers in PWRs. In reverse, the transfer of pressurization technology to BWR fuel rod fabrication and the implementation of improved safety analysis methodology for BWRs was facilitated by the close proximity of PWR experience.

Another advantage of the multi-product plant is the flexibility which allows the design and fabrication of fuel which is closely matched to the operating requirements of the individual customer. In addition, both the broad range of production experience and the design of fabrication equipment have combined to allow rapid introduction of new fuel configurations with minimal negative impact on production.

Along with the competitive benefits of a flexible product line, there are a number of challenges which accompany product flexibility. These include:

- Timely and accurate transfer of information between organizations during the planning phases of fabrication projects;
- Control of inventory;
- Accurate scheduling with rapid feedback of production status;
- Control of quality;
- Innovative design of work station equipment and tooling to allow rapid changeover between product lines;
- Efficient machining of small lots with tight tolerance and complex parts;
- Effective personnel utilization.

TRANSFER OF INFORMATION

The initial planning of a project involves a number of organizations including Marketing, Fuel Design, Purchasing, Quality Control, Production Control, Engineering, and Manufacturing. The flow of information between organizations is assured through the use of a tightly controlled, formal routing and sign-off system for the various design documents such as product specifications, parts lists, and design drawings and other documents (up to 42 documents for a typical reload). This routing system is under the control of full time project coordinators with the responsibility for maintaining review and sign-off schedules in relation to the fabrication schedule. A computerized, online project management program is used to schedule and track the overall project.

CONTROL OF INVENTORY

Approval of the final parts list for a project (generally 12 months prior to start of fabrication) establishes a common data base consisting of the 75 to 100 parts and subassemblies used in the fabrication of a typical ANF fuel bundle. A computerized Manufacturing Resource Planning (MRP) system introduced in 1983 has proved to be an invaluable tool for a multi-product plant manufacturing integration. Program modules from this system are used to plan and track the procurement or fabrication of 4,500 different items, sourced in Europe as well as the U.S.

The detailed materials planning and control modules, along with the purchasing and bill of materials modules have been combined to significantly improve hardware availability and allow the application of just-in-time inventory materials. This has resulted in an increase in inventory turnover rates. Rates of six turns per year, as compared to a U.S. industry-wide average of approximately three turns per year, are being achieved.

SCHEDULING AND PRODUCTION FEEDBACK

Computerized control in other areas such as Process and Routing (PRS) and Shop Floor Control (SFC), have provided significant improvement in scheduling of the fuel fabrication and in-house component machining and assembly operations. Computer-generated manufacturing order/follower cards are issued to the shop to initiate the fabrication sequence. In addition to identifying the material being processed, a follower card identifies the sequence of process and inspection steps to be followed, as well as the equipment to be used and the job specific tooling, and acknowledgments that the steps have been completed.

Work completed on a project is updated in the Shop Floor Control computer program by manual batch data entry, through centrally located computer terminals. Keys to flexible manufacturing are rapid dissemination of accurate data and ease of data collection. The Rod Serialization System, one of three ANF developed data collection and processing systems is presently in the final phases of implementation. A feature of Rod Serialization is the recent addition of bar code reader terminals at each workstation in the Richland fuel rod fabrication and bundle assembly areas. These terminals allow real time update of Shop Floor Control by the station technician. This latter system, along with the recently completed Bundle Assembly Data Logger system, are designed to record the progress of individual fuel rods and assemblies through the shop.

The Bundle Assembly Data Logger system, working from a computerized bundle loading program, prompts the machine operator on the correct order of selection for each fuel rod type used in an assembly. Upon an initial read of each rod's bar coded serial number, the status of the rod is checked to determine that it has been released by Quality Control for assembly, that the number is not a duplication, that it is the correct part number, and that it has been selected in the order called for in the assembly sequence. A second check is performed immediately before insertion of the rod into the bundle to verify the initial reading and that the rod order has not been altered. X-Y position transducers provide feedback to the computer of the inserted position and a real-time printed record is made of rod serial number and rod location within the bundle. On completion of a bundle, a complete map is printed for QC records and the nuclear materials accountability system is automatically updated through the computer link. The flexibility of Bundle Assembly Data Logger system allows rods to be assembled in any pattern or order selected at the start of a project. Both PWR and BWR designs are easily accommodated.

A third project, Container Serialization, will provide computerized, real time tracking of uranium containers from the receipt of UF_6 cylinders entering the plant until the uranium is loaded into fuel rods. These systems, which rely on reading of bar codes attached to the materials as they enter and leave a workstation or storage location, are capable of providing data on material location and type, processing history, and release status. The latter three systems also have provisions for control of deviant material and can determine whether serialized components match the parts list callout for an assembly or subassembly being fabricated at any workstation. Failure of components to match properly causes a station alarm to notify the operator to shut down processing until the mismatch is corrected.

Each of these three systems is designed to minimize shop labor for collecting the three to four million data entries formerly recorded manually each year. Highly accurate bar code label readers are used wherever possible to speed data entry.

QUALITY CONTROL

The Quality Control program at ANF requires extensive inspection of numerous components produced in-house or procured offsite. Some components, i.e., tie plates, spacers and pellets, require 100% inspection of key attributes. In order to meet the inspection requirements of the plant, an inventory of approximately 5,000 gauges is maintained. Nearly one-fifth of these gauges are functional gauging, an inspection technique which efficiently determines the dimension acceptability of a feature or set of features without direct measurements.

The basic types of functional gauging used at ANF are as follows:

- Go-no-go pins;
- Computer-generated templates;
- Ring gauges;
- Gauging for compatible reactor interface;
- Gauging for specific features on such items as tie plates, spacer grids, leaf springs, end caps, etc.

A computerized gauge inventory system has been developed at ANF to identify functional gauging for each job. This system also has a time-in-use feature which tracks each gauge and provides notification of reinspection dates.

QUALITY CONTROL OF PURCHASED PARTS

ANF's product specifications have consistently imposed stringent quality requirements on vendors, and one of these requirements has been to prepare an inspection and test plan for purchaser approval. However, during 1983 ANF determined that many vendors were having difficulty complying with the inspection and test plan requirement. Further, with a large number of procurements involving a variety of component designs, it was not an easy task to monitor submittal and approval of these plans. The decision was made to prepare inspection and test plans for each component, maintain them in a computer file, and provide them to vendors via the component purchase order.

The plans are maintained in the computer and are easily updated as changes are needed because of drawing or specification changes. The plans are called up on the CRT screen and the change is simply entered; the revised plan is then approved and issued. Changes requested by the vendors are implemented in a similar manner.

Instructions for use of the plan are included in each purchase order. The instruction normally used is shown in an attachment to the purchase order. As specified in the instruction, the vendor may propose alternate inspection methods for approval.

ANF's experience to date with the computerized vendor inspection and test plans has been very positive. Vendors have become very accustomed to their use and found that it greatly reduced problems in establishing vendor inspection and test plans. Receipt inspection personnel are now receiving an acceptable inspection record from the vendor, in a consistent format, and have experienced a significant reduction in problems related to reviewing the vendors inspection data.

Each purchased component has an ANF-approved inspection and test plan for use by the vendor. In the past, vendors performed inspections as required by the purchase order, but were inconsistent in preparing formal plans for approval.

Vendor inspection records are more complete and understandable. ANF plans that are used as the form for inspection records guide the vendor on what is expected, and therefore improve the chances of the vendor providing an acceptable inspection record.

The vendor's inspection methods are as consistent as possible with those to be utilized by ANF during receipt inspection. Proper implementation of the agreed upon methods results in acceptable product quality, and few vendor/receiver differences.

The vendor's confidence is improved that components will be accepted by ANF. ANF advises the vendor of preferred inspection methods, and proper utilization of these methods by the vendor assures that components will be acceptable for use.

Receipt inspection efficiency is improved because fewer problems need to be resolved concerning the vendor inspection record. Also of major importance is the improved efficiency in preparing the receipt inspection record. In order to provide a detailed receipt inspection, ANF's previous practice was to record various inspected characeristics on an inspection report. Now, the characteristics are always listed on the computerized inspection report received from the vendor. Recording of characteristics is not required as the inspector only needs to check off whether Receipt Inspection found the characteristics acceptable or not. The number of inspection records is reduced as both the vendor and ANF record their inspection results on the same form.

The inspection plans all show the methods and equipment to be used, therefore providing efficient guidance for both the vendor and ANF inspector to use in preparing for inspection.

Using the computerized inspection and test plan for the vendor's inspection record allows ANF to control the reproducibility of the inspection record. Legibility problems are minimized, and the inspection record represents a complete and reproducible record of characteristics inspected.

One of ANF's main objectives is to produce a quality product which meets with customer satisfaction. The manner in which this is done must also strive for clarity and traceabiity in line with customer requirements. Naturally, an inspection record that presents the methods of inspection along with vendor and ANF inspection results in a concise and easy to audit manner is preferred by the customer.

WORK STATION DESIGN

In addition to the challenges of maintaining effective communication between organizations, establishing accurate schedules, managing inventory and streamlining the transfer of data, the multi-product plant demands careful consideration of workstation design, station layout, material flow and tooling design.

A flexible manufacturing operation generally requires greater capital investment for equipment per unit of product than operations of more limited variety. The choice is between multiple, single-product lines or fewer, more complex workstations, capable of handling the full range of products. The latter course has been chosen by ANF, driven to a large extent by the high cost of additional shop floor space, built and operated to nuclear industry standards. Multiple use of floor space, i.e., operating personnel access, material handling and queuing room, and maintenance access is the standard.

Aside from processing some 80 separate uranium enrichments annually, the impact of a mixed BWR-PWR product line is minimal in the chemical conversion end of the UO_2 plant. Variations in pellet size and rod dimensions exercise a major influence on operation of the pellet fabrication, rod fabrication and bundle assembly areas. As an example, ANF maintains an inventory of press tooling valued at over one million dollars to accommodate 135 variations in pellet configuration. Management of this pellet tooling inventory, as well as tooling required for the rod loading and welding, spacer fabrication, and bundle assembly workstations requires a systematized approach. Tooling requirements are first identified by the Methods Engineering organization during the formal design document review previously discussed. Control numbers assigned to the tooling are identified in the computerized resource planning system. These data are used to generate a tooling pick list, through a separate equipment resource management computer system, and the list is issued to manufacturing prior to the start of each fabrication project.

MACHINING CAPABILITIES

ANF maintains its own in-house machine shop to fabricate or complete fabrication of critical components. Extensive use of numerical control equipment provides manufacturing flexibility, rapid switchover between various part designs, efficient machining of complex designs, and a high degree of precision.

As an example of complex designs with tight tolerance requirements, the various tie plate configurations have numerous features which must be maintained within 0.002 inch. CAM (Computer Assisted Machining) is combined with the use of functional quality control gauging to efficiently manufacture these parts.

PERSONNEL UTILIZATION

Support of multi-product manufacturing requires a high degree of operator cross-training on multiple workstations. Over 70% of ANF's production personnel are trained on five or more workstations. The flexibility afforded by a staff of highly trained, multi-skilled operating technicians allows movement and concentration of manpower to compensate for variations in workstation throughputs and alternative product flows. As an example, the ANF process for fabrication of BWR fuel rods calls for chemical etching and autoclaving of rods before inspection and assembly into bundles. PWR production does not include these process steps. Thus, during a predominantly PWR product schedule personnel normally used for etching and autoclaving BWR rods can be utilized in other operations such as rod loading and tube cleaning.

Flexibility in work assignments has the added benefits of work force economy, providing stable employment, and decreasing personnel turnover. Job content and interest are also higher with multiple station assignments.

Both opportunities and challenges are presented by a multi-product BWR-PWR manufacturing operation. The benefits are technology transfer, closely tailored fuel designs, and rapid response to product changes. The challenges are innovative equipment designs, cost control, staff training, and maintaining a responsive communication system.

LICENSING AND ENVIRONMENTAL CONCERNS

Increasing public awareness of the potential environmental impact of hazardous wastes, real or imagined, has resulted in an increasingly demanding regulatory atmosphere, typified by increased regulations concerning the acquisition, storage, use, and final disposition of the controlled materials. This applies to normal industrial chemicals and byproducts as well as low level nuclear waste. ANF process designs emphasize recycle streams in order to reduce or eliminate low level radioactive process waste. This has many advantages. The most significant are a reduction in the actual uranium lost, or requiring secondary recovery processes, and the ability to discharge to the sewer eliminating or reducing the regulated materials.

The ANF recycle process uses ion-exchange to recover the uranium from the process water. The process water is then discharged to a covered holding pond from which the ammonia is recovered and recycled as feed to the UF_6 to UO_2 conversion process.

Systems are also in place to recover uranium from evaporation lagoons that were used to store process waste water prior to the installation of the process water treatment equipment.

ANF also believes that there are still opportunities to reduce losses and/or to reduce the bulk of the solid wastes generated in the normal course of manufacturing fuel. ANF is currently installing incineration equipment to reduce the bulk of this waste and to simultaneously dispose of hazardous chemicals within regulatory guidelines. Concurrently ANF is developing ash leaching processes that will recover the contained uranium.

ANF has maintained airborne contamination as low as reasonably achievable. This has resulted in average airborne concentrations of 5.4×10^{-12} µCi/ml which is far below both current and proposed exposure regulation limits.

PROSPECTS FOR IMPROVED PROCESS TECHNOLOGY

Dry Conversion

ANF has developed a dry conversion process for converting uranium hexafluoride into ceramic-grade uranium oxide powder, which has several advantages over other dry processes. The process has been under development for the past five years, and has been successfully demonstrated in a pilot plant and a near full scale production unit. The final phase of our development activity is the irradiation of statistically significant quantities of pellets produced from the process.

The feasibility of this process was demonstrated in 1983. Fuel rods, both full length and segmented, containing enriched dry conversion pellets have been assembled and are being irradiated in five commercial reactors.

The dry conversion process is expected to totally replace the existing Ammonium Diuranate (ADU) process. Dry conversion not only provides the advantage of eliminating an aqueous waste stream, but tests indicate the product has less lot-to-lot variation and yields a product with better physical characteristics and improved pellet qualities. The dry conversion waste stream consists of a concentrated hydrofluoric acid which is suitable for reuse.

The principal process improvement is the improved lot-to-lot uniformity of the dry conversion powder which may allow pressing and sintering parameters to be fixed as opposed to the current practice which utilizes lot specific process parameters, thus eliminating or minimizing expensive and time consuming lot characterization tests.

Ceramics and Fuel Assembly

Demand for fuel designed for higher and higher burnup will add more stringent requirements. Process and manufacturing technologies are being developed to meet these challenges.

Reprocessed Uranium - Mixed Oxide

Fuel manufacturing facilities incorporating capability for processing mixed oxide and/or reprocessed uranium will be required for countries which opted for fuel reprocessing.

Waste

Continued emphasis will be placed on controlling waste effluent including recycle and rework.

MANUFACTURING TECHNOLOGIES

Flexibility in Manufacturing

Continued emphasis on multi-product lines is anticipated.

Inventory Control

Just-in-time material control and the incorporation of computerized scheduling of shop floor material routings is expected to continue at a greater level.

Quality Control

Significant improvements are anticipated in automation and computerization of inspection techniques, including the use of real-time devices with rapid feedback-loops for control of processes.

Automation

Fuel manufacturing plants of the nineties will incorporate a high degree of automation while maintaining flexibility with the goal of producing a consistently high quality product at a competitive price.

Personnel Utilization

The utilization of plant personnel in a highly-automated and computerized manufacturing operation offers great challenges. The training of personnel to meet the needs of more highly-automated and computerized operations can, and will, be accomplished.

Prospects for the nineties indeed appear to be challenging with great opportunities for nuclear fuel manufacturers. The market place will continue to be extremely competitive, demanding a high quality product at a competitive price. With the recent advances in fuel fabrication techniques and planned future commitments, significant advances are anticipated in the fuel manufacturing business that will continue to meet the needs of the nuclear utility industry.

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