PRODUCTION PROCESS AND QUALITY CONTROL FOR THE HTTR FUEL

S. YOSHIMUTA, N. SUZUKI, M. KANEKO
Nuclear Fuel Industries, Ltd,
Tokai-mura, Naka-gun, Ibaraki-ken

K. FUKUDA
Japan Atomic Energy Research Institute,
Tokai Research Establishment,
Tokai-mura, Naka-gun, Ibaraki-ken

Japan

Abstract

Development of the production and inspection technology for High Temperature Engineering Test Reactor (HTTR) fuel has been carried out by cooperative work between Japan Atomic Energy Research Institute (JAERI) and Nuclear Fuel Industries,Ltd (NFI). The performance and the quality level of the developed fuel are well established to meet the design requirements of the HTTR.

For the commercial scale production of the fuel, statistical quality control and quality assurance must be carefully considered in order to assure the safety of the HTTR. It is also important to produce the fuel under well controlled process condition. To meet these requirements in the production of the HTTR fuel, a new production process and quality control system is to be introduced in the new facilities. The main feature of the system is a computer integrated control system. Process control data at each production stage of products and semi-products are all gathered by terminal computers and processed by a host computer.

The processed information is effectively used for the production, quality and accountancy control. With the aid of this system, all the products will be easily traceable from starting materials to final stages and the statistical evaluation of the quality of products becomes more reliable.

1. Introduction

NFI itself started the development work of High Temperature Gas-cooled Reactor fuel in 1964. The basic production process was developed in a laboratory scale at the early stage of the development, and a pilot plant with the capacity of about 40 kg/year was established in 1972. The fuels produced in this plant were submitted to the irradiation experiments and out of-pile evaluation tests planned and performed by JAERI.

In 1983, the production capacity was expanded to 200 kg/year and the fuel compacts (about 260kg-U) for Very High Temperature Reactor Critical Assembly owned by JAERI were produced in a period of two years.

Through these experiences development of production and inspection technology has been proceeded cooperatively between JAERI and NFI, and the quality of the fuels could be improved.

The first core fuels (about 900 kg-U) for HTTR are planned to be produced in a period of three years from 1992. The new production facilities will adopt a computer integrated control system which will play an important role in quality assurance, statistical quality control, process control and uranium accountancy.

This report focuses especially on the production process and quality control system for the HTTR fuel.

2. Production Process

The basic structure of the HTTR fuel is a pin-in-block type, as shown in Fig.1. The fuel compacts, in which the coated fuel particles (about 13000 particles) are homogenously dispersed, are formed into cylindrical shape with centerhole. The coated fuel particle loading fraction in the fuel compact is 30 vol-%. The fuel rods, containing 14 fuel compacts in the graphite sleeve, are inserted into the coolant channels prepared in the hexagonal-shaped graphite block. About 70000 fuel compacts will be loaded in the HTTR core.

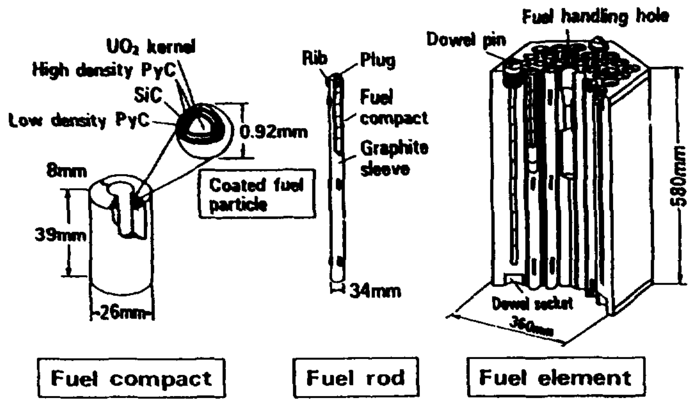

Fig.1 STRUCTURE OF HTTR FUEL

2.1 Fuel Kernel

The UO_2 fuel kernels are produced following the well-known gel precipitation process with some modification as shown in Fig.2. The material solution, uranyl nitrate $UO_2(NO_3)_2$, is mixed with additives to control the characteristics such as viscosity. Small spherical drops are produced by the vibrating nozzles and are solidified during the fall in NH_3 gas. Ultimately these are aged in ammonia solution to form spherical ammonium diuranate (ADU). Following washing by H_2O and alcohol, and drying, ADU particles are calcinated to form UO_3 and then sintered to produce UO_2 fuel kernels. The diameter of a UO_2 fuel kernel depends on that of the drop which are controlled by the flow rate of the uranium solution and the frequency of the vibrating nozzle. The diameter of a UO_2 fuel kernel is 600 μm and the density is 10.41 g/cm³.

2.2 Coated Fuel Particle

The coating process of TRISO type coated fuel particles is shown in Fig.3. The innermost first layer is low density pyrocarbon, the second layer and outermost fourth layer are high density pyrocarbon and the third layer is silicon carbide. The coating

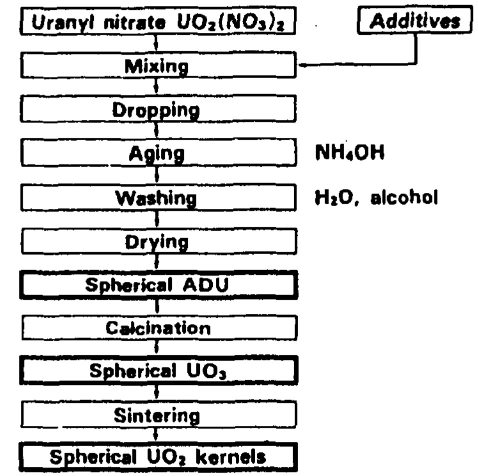

Fig.2 PRODUCTION PROCESS OF UO_2 KERNEL

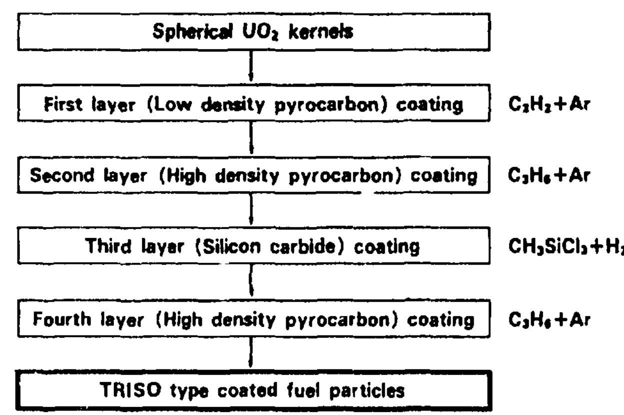

Fig.3 COATING PROCESS OF UO_2 KERNELS

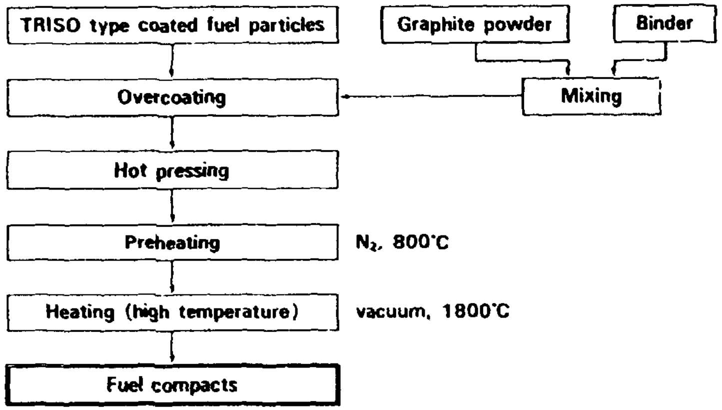

Fig.4 PRODUCTION PROCESS OF FUEL COMPACTS

of fuel kernels is performed in the coater. Acetylene for low density pyrocarbon layer, propylene for high density pyrocarbon layers and methyltrichlorosilane for SiC layer are used as the pyrolysis or decomposition materials.

2.3 Fuel Compact

Fuel compacts are produced following the process shown in Fig.4. Mixing the resin binder components, phenol and alcohol, with graphite powder and grinding the mixture to the controlled grain size, resinated powder can be obtained. The resinated powder is then used to overcoat the coated fuel particles. After weighing the resinated powder ratio to the overcoated particles, sieving, separating odd shaped overcoated particles and drying, the overcoated particles are fed to the pressing machine to produce green fuel compacts. The overcoated particles per fuel compact is weighed to adjust the uranium content using an automatic weighing instrument and then these are automatically charged to the dies by a handling robot. The discharge and arrangement of green fuel compacts are also carried out by a handling robot.

Each green fuel compact is automatically marked by an ink jet printer to identify the enrichment and serial number. They are then preheated to carbonize the binding agent at 800℃ in N_2 gas atmosphere and heated at 1800℃ in vacuum.

2.4 Fuel Rod

A fuel rod consists of a graphite sleeve with one end closed, fuel compacts which are stacked in the sleeve, carbon wool buffer and a graphite end plug, which is screw connected to the open end of the sleeve. The sleeve has three circumferential outward spacers to form coolant He gas flow area in the fuel hole provided in hexagonal-shaped graphite block.

12 kinds (3.4~9.9 wt-%) of ^{235}U enrichments are planned in the HTTR core. So, to prevent the loading of a wrong fuel rod into the block, the rib on the sleeve and the corresponding groove on the fuel hole of the block are adjusted for each enrichment.

3. Quality Control

Product quality of coated fuel particles plays a very important role for the performance and the safety of the reactor core. The core contains a large number of small spherical coated fuel paticles, and each particle has its own fission barrier. So, the production of the fuel is needed to be done under sufficiently controlled process conditions and quality assurance procedures to meet design specification. To meet these requirements, NFI has been developing a computer integrated control system for production process and quality control. This system is expected to provide positive benefits for quality assurance, statistical quality control, process control and uranium accountancy.

3.1 Process and Quality Control Data

Main process and quality control items at each production stage are shown in Fig.5. The conditions to be controlled at each production stage consist of many process control

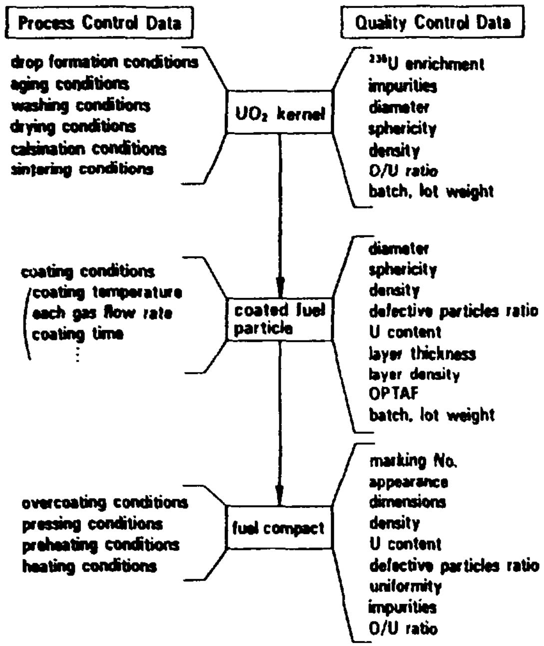

Fig.5 MAIN PROCESS AND QUALITY CONTROL DATA

items. For example, the drop formation conditions at UO_2 kernel production process consist of process control items such as flow rate, viscosity and temperature of uranium solution, frequency of vibrating nozzle, flow rate of NH_3 gas, etc.

Quality control data are also obtained by many and different kinds of inspections to satisfy the specification and the governmental regulatory criteria.

These process and quality control data should be processed quickly and exactly to reflect to the on-going production, and therefore, it is necessary to be assisted by computers. It is also desirable that the production and inspection methods are automated. For example, the layer thickness of the coated fuel particles can be measured by a picture processing equipment making use of X-ray photograph of coated fuel

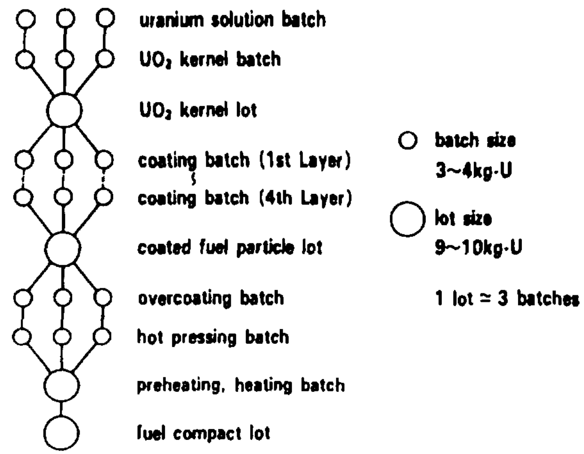

Fig.6 LOT FORMATION OF FUEL PRODUCTION

particles. The dimensions, weight and uranium content of fuel compacts can be measured continuously using automatic measuring instruments and a handling robot, and finally fuel stack are arranged according to these obtained data.

3.2 Lot Formation of Fuel Production

Because of the difference in batch size at each production process step and to make the quality of products uniform, a lot formation plan, as shown in Fig.6, is applied. A lot is formed by mixing uniformly the products from plural batches (1 lot=about 3 batches) at each production process stage and samples for inspection are taken from the lot. From the quality control data of the samples the characteristics of a lot, namely that of plural batches, are estimated. The lot size of the final fuel compacts is 9kg-U. Complicated control of the lot formation from plural batches is also assisted by a computer. The history of the products are recorded with batch and lot numbers at each production stage. As a result, the recorded data including process control and quality control items can be traced automatically, if necessary, after completion of the fuel element.

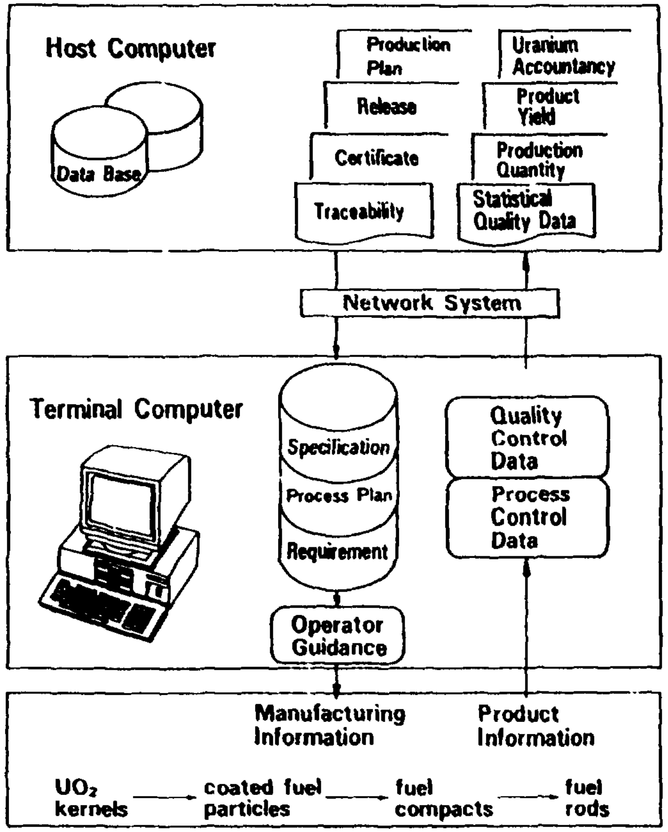

Fig.7 OUTLINE OF THE PRODUCTION AND QUALITY CONTROL SYSTEM

3.3 Outline of the Production and Quality Control System

The production and quality control system under development is a computer integrated control system. The outline of this system is shown in Fig.7. This system is divided into two levels consisting of a host computer and terminal computers. The host computer is linked with terminal computers by the network. The host computer gives instructions relating to the specifications, process plan and requirements to any terminal computers at each production process stage. The operators at each stage recceive the needed information for production from the terminal computers. Product information relating to process control and quality control are gathered and registered at each production stage by the terminal computers, and these are fed to the host computer. For the objective of accountancy, product quantity and product yield are also calculated. The host computer can comprehensively track the process and quality control data of every semi-products and products, therefore this system can easily trace the quality data at the previous steps of the production process. Because of the rapid feedback of quality data to the terminal computers at each production process stage, quality levels of the products can also be easily stabilized. Quality control data are all checked by comparing them with the predetermined control limits for the release of products to the next process and are finally provided for the preparation of inspection certificates.

3.4 Functions of Production and Quality Control System

As shown in Fig.8, the functions of the production and quality control system are divided into three categories, namely production and process control, quality control and accountancy. Each function includes many kinds of items. For example, by performing the statistical calculations of quality control data, the reliability of quality level can be estimated.

4. Conclusion

The production process and quality control system being developed for the HTTR fuel will be effectively used for quality assurance, statistical quality control, process control and uranium accountancy which are summarized as follows :

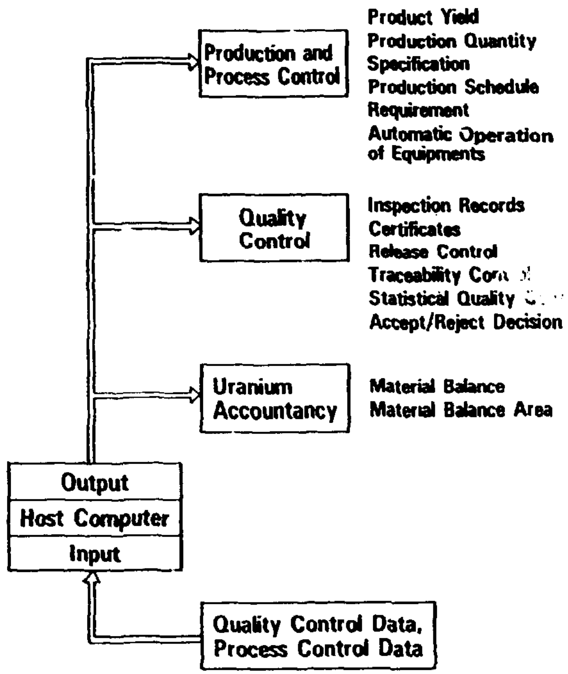

Fig.8 FUNCTIONS OF PRODUCTION AND QUALITY CONTROL SYSTEM

(1) Quality Assurance

- Production Schedule
- Release Control
- Traceability Control
- Preparation of Inspection Certificates

(2) Statistical Quality Control

- Registration of Production and Quality Control Data
- Statistica' Evaluation of Quality Control Data

(3) Process Control

- Accept/Reject Decision
- Production Quantity
- Automatic Control of Equipment Operation
- Required Operational Conditions

(4) Accountancy

- Material Balance and Material Balance Area