Fabrication in Mexico of Fuel Rods for Irradiation in a BWR Reactor

Carlos A. Nocetti, Enrique Velazquez
Instituto Nacional de Investigaciones Nucleares
Salazar, Edo. de México, Mexico

ABSTRACT

FABRICATION IN MEXICO OF FUEL RODS FOR IRRADIATION IN A BWR REACTOR

The Instituto Nacional de Investigaciones Nucleares with the collaboration of the Kernforschungszentrum Karlsruhe GmbH and Siemens/UB KWU fabricated 14 segmented fuel rods for a BWR reactor in the FRG. The fabrication process, quality control procedures and quality assurance system utilized is described. The fuel rods fabricated were accepted for irradiation by the Technischer Ueberwachungs-Verein of the FRG. The irradiation will be finished in March 1989, reaching a peak burn-up of 18,000 MWd/ton. The fabrication and irradiation of this fuel will permit us to qualify for the fabrication of prototype fuel assemblies for the Mexican nuclear power reactors.

1. OBJECTIVE

The Instituto Nacional de Investigaciones Nucleares (National Institute of Nuclear Research - ININ) has a long term development plan in the nuclear fuel fabrication area. The initial steps were done at laboratory scale. In 1976, we signed a collaboration agreement with the Kernforschungszentrum Karlsruhe GmbH (KfK) of the Federal Republic of Germany (FRG). Within the frame of the agreement, experts from KfK came once or twice a year to assess our progress. We built a small pellet pilot plant and we looked for irradiation possibilities to test our fabrication capabilities.

In 1980, we fabricated 5000 natural UO₂ pellets for the MZFR (PHWR type, 57MWₑₑₑₑ), power and research reactor located in Karlsruhe, FRG. We purchased the specifications from the reactor supplier and developed the fabrication, quality control and quality assurance technology. The pellets were accepted for irradiation in the FRG by the Technischer Ueberwachungs-Verein (TUv). They were irradiated from May 1981 to August 1983 reaching a burn-up of 9640 MWd/ton. The behavior was absolutely normal.

In 1983, the pilot plant was enlarged adding the rod fabrication area where we produced 31 fuel rods (Nocetti, 1986) in 1984, for irradiation in the MZFR -- reactor. We followed the same system of developing the technology with KfK assistance. The rods were accepted in our facility for the Baden Office of the TUv but could not be irradiated because the reactor was unexpectedly decommissioned just before we finished the rods.

KfK and Siemens Unternehmensbereich KWU (KWU) obtained for us the possibility of irradiating one segmented fuel rod in the Brunsbüttel reactor (BWR type, 806MWₑₑₑₑ). In this way, we could add the difficulties of handling enriched UO₂ and testing

53
our fuel to a higher burn-up.

2. METHOD

The segmented fuel rods had 384.2 mm in length and one full length fuel rod was formed with 7 segments. KWU supplied the specifications and KFK donated the materials. We started with free flowing, 2% enriched UO$_2$, Zircaloy-2 tubes and end plugs, alumina and natural UO$_2$ insulating pellets and springs, supplied by Siemens Brennlementwerk Hanau (RBU).

A project manager directed two independent groups: Fabrication and Quality Control (Q.C.). Calibration was included in the Q.C. group but its personnel could not perform the Q.C. of the fuel. The Quality Assurance (Q.A.) group was independent of the project, reporting directly to the institution management. The Q.A. Program was written (Ovilia, 1985) and we started the preparation of procedures and instructions. The qualification of equipment, of process and personnel was done with depleted UO$_2$ and materials from the same supplier. Process qualification was later repeated with the certified fabrication materials.

According to the Q.C. plan (Rodriguez, 1986) the reception and characterization tests were done on the enriched UO$_2$: Visual examination, particle size, bulk and tap density, specific surface area, flowability, oxygen-to-uranium ratio, - moisture, sinterability and chemical analyses. Powder preparation of the free flowing UO$_2$ (Torres, 1986) consisted only in adding 0.3% of zinc stearate as a lubricant for pressing. It was done in a V blender in two stages, with an intermediate sieving to separate any existing lubricant granules. The Q.C. consisted of visual examination, bulk and tap density and flowability.

The pellets were pressed (Torres, 1986) in a 40 ton mechanical press with floating die. The die was made of tungsten carbide and the punches with AISI 01-steel. The pellets had a smooth and rounded shape. The die had an exit angle of 13 min. and permitted 40% of the elastic recovery occurring inside it. 30% of the pellet volume was compacted in the die cone in order to have a longer double effect pressing, compensating the density decrease at the top of the pellet with a final top pressing. Green density was maintained between 5.4 and 5.5 gr/cm$^3$. During pressing Q.C. checked one out of 20 green pellets produced, for visual - appearance, density and dimensions. If the pellet was within specifications, the pressing could continue.

The sintering was performed in molybdenum batch furnaces using pure hydrogen atmosphere. A presintering plateau of 850°C was used for 1 hour to eliminate the zinc stearate completely. The sintering temperature was 1720°C for 2.5 hours. The pellet density was kept between 10.4 and 10.5 gr/cm$^3$. The Q.C. consisted of statistic measurement of density, microstructure and resintering properties. Wet centerless grinding with silicon carbide wheels was the next process. During grinding, one out of every 50 pellets was examined and dimensionally controlled by the Q.C. group. Washing procedure consisted of ultrasonic cleaning for 10 min. rinsing in tap and distilled water, blowing with air and drying in an oven at 130°C and vacuum better than 10$^{-2}$mbar. Finished pellet control included a - 100% verification of geometrical density, diameter, height, visual examination and statistical control of immersion density, dishing, shoulder, perpendicularity, roughness, moisture, oxygen to metal ratio, total uranium and chemical analyses of impurities. The isotopic composition, residual gas and total hydrogen content was determined at RBU because ININ did not have the necessary equipment.

The reception tests (Rodriguez, 1986) of the Zircaloy-2 tubes included 100% control of length, inside and outside diameter at the ends and visual examination and statistical control of surface roughness. The control for the end plugs, natural UO$_2$ pellets, insulating alumina pellets and springs consisted of visual appearance and dimensions. The filling gas for the rods was 99.999%, pure helium, and each cylinder came with the suppliers analyses.

Welding preparation (Cabrall, 1986) of the tube requires machining at the end, a
chamfer and a cone with very close tolerances, some in the range of 0.02 mm. The machining was controlled with short specimens measured in a profile projector. If the short specimens machined at the beginning and at the end of the series of 5 tubes were within specifications, the series was accepted. The tubes, end plugs, alumina pellets and springs were ultrasonically cleaned with acetone and then dried with hot air.

The welding was performed in an automatic system developed at the Institute (Ca bral et al, 1986). The programmable TIG power source used had pulsed current. A frequency of 25 Hz was used for the welding of the first end plug, and 20 Hz for the second one, pulsing between a maximum and minimum current with a ratio of 2. The maximum current was maintained for one third of the pulse and the -- welding cycle was formed by 4 ramps. The maximum current in the welding of the first end plug was 78 Ampere (see Fig. 1) and 90 in the second one (see Fig.2). After an initial start delay of 1 s, the tube rotation speed was 7.5 rpm in the first weld and 10 rpm for the second weld. A tungsten 2.2% thoria, 1.5 mm diameter electrode was used with a 14 ± 2° tip. The arc length was 0.25 mm for the first end plug and 0.30 mm for the second one, measured from the outside of the chamber with a stereo microscope. The welding chamber atmosphere, obtained with at least two cycles of vacuum better than 10⁻⁴mbar and helium flushing, had to
have an oxygen and moisture content better than 8 and 22 ppm in volume. The power source could not be energized until the analyzer indications reached the established values. Welding penetration ranged between 114 and 122%. The Q.C. consisted of visual comparison with color standards, measuring of welding diameter, end plug eccentricity and radiography at a 100% of the welds. The metallographic and corrosion tests were made on specimens taken at the beginning and end of the day's production and after welding 10 samples. Qualification required 15 consecutive welds within specifications. The tubes with the first end plug welded were cut to length, machined, washed and dried like before.

The pellet stack (Cabral, 1986) was prepared in a V block with 24 enriched UO₂ pellets, 2 natural UO₂ pellets at the ends and 2 or 3 alumina pellets to adjust the length. Q.C. checked the weight, number, type of pellets and column length before loading, and the plenum after loading. The tube with the first end plug welded was dried at 100°C and vacuum better than 10⁻³ mbar. The pellets were loaded and then the complete rod was dried at 200°C and at the same vacuum. The cooling was done in the furnace under vacuum. The cold rods were sealed with polyethylene plugs and welded within 24 hours. After drying, Q.C. performed visual examination, checking colors in the Zircaloy and the moisture, measured in 5 pellets taken from one of the dried rods. The coulometric electrolytic --
moisture method of analysis at 700°C was used for determination. The maximum moisture obtained was 7 ppm with respect to UO₂ weight.

The second weld was carried out as described before. Helium filling pressure was 1 atmosphere \((1.013 \times 10^5 \text{Pa})\). Inspection (Rodriguez, 1986) of the finished rods included determination of weight, dimensions, radiography of the complete rod, helium leak testing and final visual examination. Destructive verification of filling gas pressure and purity was made at RBU. Each rod was marked at the bottom end plug and followed by a travelling card with the records of the Q.C. steps already performed.

3. RESULTS

The Norddeutschland office of TÜV performed the qualification of the special -- process (NDT, 1st. and 2nd. welds and rod drying), the verification of the Q.C. of the pellets, the rod fabrication, the rod Q.C. steps and documentation control, in our facility in a 2 week inspection. Considering that the Q.A. system was appropriate, the Q.C. department was independent of the fabrication, the -- personnel was qualified and the fabrication and Q.C. equipment was appropriate, ININ was accepted as fuel fabricator for the segmented fuel rods, and then the 14 rods produced, could be irradiated in the reactor. KWU performed its own audit at the same time as TÜV.

One rod was assembled at RBU with 7 of our segments and placed in a KWU test fuel assembly. The irradiation started on August 24, 1986 and will be completed at the end of March 1989. The average burn-up reached will be 15,000 MWD/ton and the peak burn-up 18,000 MWD/ton. The behavior so far has been absolutely normal. The final assessment of the behavior will be obtained after the postirradiation examination scheduled for the beginning of 1990 in KFK hot cells. The data obtained will be used to model the rod behavior in the SAMURA-ININ code - (Samiei, 1981) partially developed in the fuel group.

4. CONCLUSIONS

The results obtained have demonstrated through 2 successful irradiations that our institution can be qualified as a fuel supplier of small amounts of water reactor fuel. Our next job, now under preparation, is to fabricate 8 prototype fuel assemblies for the Mexican Laguna Verde reactors (BWR type, 654MWe). This time we will have a complete technology transfer from a fuel fabricator.

REFERENCES


57