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TECHNICAL EVALUATION REPORT FOR THE REQUALIFICATION OF SPERT FUEL FOR USE IN NON-POWER REACTORS

R. R. Hobbins

Prepared for the
U.S. NUCLEAR REGULATORY COMMISSION

EG&G Idaho

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ABSTRACT

This report evaluates the requalification of SPERT fuel pins for use in non-power reactors. The requalification of SPERT fuel was performed by Argonne National Laboratory to verify that the pins have suffered no physical damage since fabrication. Pins were inspected under 6X magnification, and by x-radiographic, destructive, and metallographic examinations. Spectrographic and chemical analyses were performed on the UO_2 fuel. The requalification results give reasonable assurance that the SPERT fuel rods are suitable for use in non-power reactors provided that the effects of thin-wall defects in the region of the upper end cap and low-density fuel pellets are evaluated for the intended operating conditions.

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TECHNICAL EVALUATION REPORT FOR THE REQUALIFICATION OF SPERT FUEL FOR USE IN NON-POWER REACTORS

INTRODUCTION

Some universities are considering converting their non-power reactors to low enrichment fuel by use of stainless steel clad, UO_2 fuel pins manufactured in the 1960s for use in the Special Power Excursion Reactor Test (SPERT) program. The 600 SPERT fuel pins, whose serial numbers cover virtually the entire range of serial numbers of the 9000 pins produced, were examined in the requalification program conducted by Argonne National Laboratory (ANL).[1] The 600 pins examined by ANL had never been used in a reactor and had been in air-conditioned storage at Purdue University since 1974. There is no record of the storage conditions between 1965 and 1974. The results of the ANL requalification program should be applicable to the entire production run of SPERT pins, except for pins that have been operated in reactors or stored in water or under other conditions significantly different than the storage at Purdue. In these cases, examinations for corrosion of the cladding, both surface and intergranular, may be needed. Additional examination requirements for pins that have been used in reactors may need to be addressed on a case-by-case basis, depending on operational history.

REQUALIFICATION OF SPERT FUEL

The SPERT fuel pins originally were procured according to Phillips Specification No. F-1-SPT, which incorporates Phillips Drawing No. SPT-E-1166. The component materials were required to meet applicable ASTM standards; extensive acceptance tests and inspections were required for components and the finished pins. In particular, all pins were to be inspected for dimensions and surface condition, helium leak tested to ensure the integrity of the welds (the pins were filled with helium at the time of welding), and gamma scanned to check the fuel zone length and detect the presence of any foreign materials in the fuel zone. However, it appears that all fabrication, inspection, and acceptance records have been discarded. The purposes of the requalification program were to verify that the pins are those procured to Specification No. F-1-SPT, and that the pins have suffered no physical damage since fabrication.

All 600 pins were checked for straightness and examined under 6X magnification for nicks, scratches, and/or other damage to the cladding surface. Thirty rods were measured to check diameter and roundness. All pins appeared to be in excellent condition and met the dimensional and surface condition requirements of the specifications, except (possibly) for the diameter in the end cap welds that, on the average, is 0.0041 in. (0.10 mm) larger than the maximum dimension for the pin diameter given on the specification drawing.

Sixty pins were selected randomly among the representative groups of serial numbers for x-radiographic examination of the upper and lower end cap welds. Defects were found in the upper end cap welds on six pins. The x-radiography examination found the minimum wall thickness in the defects to vary from 0.005 to 0.015 in. (0.13 to 0.38 mm) [nominal cladding wall thickness is 0.020 in. (0.51 mm)]. Metallographic examination of one of the weld defects revealed it probably was caused by a gas bubble. Although this particular defect was not connected to the interior volume of the fuel pin, radiographs of other pins showing similar defects indicate that some of the defects are probably connected to the interior volume. These defects would not have been discovered at the time of fabrication because x-radiography was not specified.

Thin wall defects tend to produce stress concentrations at the defects. The effects of such stress concentrations should be evaluated for the intended use of the fuel pins. Factors such as differential pressure across the wall of the fuel pin during normal operation and under postulated accident conditions, fuel handling practices, and corrosion control should be considered. For some uses, 100% x-radiographic inspection to eliminate pins with thin wall defects may be advisable.

The internal pressure, void volume, and fill-gas composition were measured in five pins chosen for destructive examination, in addition to the pin whose weld defect was examined metallographically. All six pins had a positive pressure of fill-gas, ranging from 0.6 to 3.3 psig. For comparison, the specification for fill gas was 1 psig of helium. The fill gas was predominantly helium, but a sizable amount of hydrogen was also found (up to 16%). Trace amounts of water vapor and nitrogen were measured, although in one pin about 1% nitrogen and a few milligrams of water were found. The hydrogen is responsible for the overpressure in the pins. The hydrogen probably resulted from the reaction of water vapor with the fuel and the cladding. Less than 2 mg of water is required to produce the amounts of hydrogen measured in the fill gas. The specification allowed up to 75 ppm water in a fuel pin, which corresponds to about 60 mg. The presence of hydrogen in the fill gas has no deleterious effect because its thermal conductivity is nearly the same as that of helium. The other minor deviations in composition and pressure relative to the specifications have no significance for the use of these pins in non-power reactors.

The entire stack of 60 fuel pellets was examined from 2 pins, and the top 6 pellets were examined from 2 other pins. All pellets examined, with three exceptions, had only minor surface chips and were judged to meet the pellet surface condition requirements of specification F-1-SPT. Three pellets in one pin each had a significant piece (0.2, 0.2, and 0.7 g, respectively) spalled off the entire length of the pellet. The missing material was contained in loose fragments and powder collected after all the pellets were removed from the pin. The length, diameter, and weight of each of the 132 pellets removed from the four pins were measured and the pellet density calculated based on solid, right, cylindrical geometry. Neglecting the three chipped pellets, sixteen pellets were found with densities outside the specification of 9.97 g/cm^3 minimum density and ±0.1 g/cm^3 deviation from the mean. Four pellets at the top of one pin were found with a density of about 9.52 g/cm^3. Excluding these four pellets and the three chipped pellets, the mean pellet density was 10.078 ± 0.055 g/cm^3. Twelve pellets in one rod had densities more than 0.1 g/cm^3 above the mean density, the largest of which was 0.15 g/cm^3 higher than the mean. With the exception of the four pellets with a relatively low density (9.52 g/cm^3), deviations of this magnitude from the specification for pellet density have no safety significance for the use of the SPERT fuel in non-power reactors. It is assumed that the pin with the four low-density pellets at the top of the fuel stack was purposely loaded in this manner and that the use of pellets with nonconforming densities was properly approved. Depending on the reactor power levels, low-density fuel pellets tend to run at higher temperatures, are subject to densification, enhanced fission-product release, and can promote exaggerated cladding collapse and pellet-cladding mechanical interaction. The presence of low-density fuel pellets in other fuel pins and at other stack locations cannot be ruled out with the current limited data base on fuel pellet density. The effects of low-density pellets should be evaluated for the intended use. Additional pellet density measurements to ensure that low-density pellets are an unlikely occurrence may be needed.

Three pellets, one from each of three rods, were sectioned and examined metallographically. The microstructures were similar in the three pellets and were relatively fine grained (5 to 10 μm) UO_2 with some porosity and, possibly, some U_4O_7 present. The structures are fairly typical of as-fabricated, unirradiated UO_2 fuel.

Analyses of uranium isotopes, total uranium, and impurities in the UO_2 fuel were performed. Spectrographic analysis for 20 elements revealed an impurity content of <185 ppm, which is only about 5% of the allowable level; however, a number of possible significant elements were not analyzed. An upper limit value of the oxygen/uranium ratio of 2.04 was calculated, based on the measured uranium content, measured impurity content, and the assumption that the remaining sample weight must be oxygen. An additional impurity content of 1200 ppm, which would be well within the specification, would result in an oxygen/uranium ratio of 2.02, which is the specified upper bound.

Metallographic examination of the fuel rod cladding showed the cladding to be within specification for wall thickness; to be seamless, as specified; and to have a microstructure typical of 304 stainless steel with some evidence of normal carbide precipitation, but no evidence of intergranular attack or corrosion from either the inside or outside surfaces. Chemical analysis showed that the metallic constituents of the stainless steel were all within the specification with the exception of cobalt, which was 0.084 wt% compared to a maximum allowable of 0.05 wt%.

CONCLUSIONS

It is concluded that the ANL examinations give reasonable assurance that these SPERT fuel pins were fabricated in accordance with Phillips Specification No. F-1-SPT, and that they substantially met the acceptance criteria when fabricated. Furthermore, the examinations show that storage for more than 20 years has not caused deterioration to cladding or pellets that would significantly affect safety in the use of these fuel pins in low power reactors. Therefore, these fuel pins are acceptable for use if the operating conditions do not cause undue stresses in the cladding. At high reactor power levels, there might be some concern because of the presence of thin-wall defects and low-density fuel pellets, but these factors should be evaluated for the intended fuel use on a case-by-case basis. The deviations from such specifications as pin internal pressure and fuel oxygen/uranium ratio are minor and without significance from a safety standpoint. The absence of intergranular attack or corrosion of the stainless-steel cladding during storage, and the basic conformance of the stainless-steel cladding to the specifications, suggest that corrosion is an unlikely failure mechanism provided there is reasonable water chemistry control.

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