# BN-350 CORE AND BLANKET FUEL CONDITION AFTER IRRADIATION AND WET STORAGE

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# СОСТОЯНИЕ АКТИВНОЙ ЗОНЫ И БЛАНКЕТНОГО ТОПЛИВА БН-350 ПОСЛЕ ОБЛУЧЕНИЯ И ВЛАЖНОГО ХРАНЕНИЯ

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The Republic of Kazakhstan is being assisted by the U.S. Department of Energy in preparing spent fuel from the BN-350 fast reactor for long term dry storage. As a precursor to this task the physical condition of a representative set of core and blanket assemblies after irradiation and wet storage for 5-20 years was assessed in the hot cells at the reactor site in Aktau and in the National Nuclear Center hot cells in Alatau. Examination methods used in Aktau included visual inspection, photography, gamma-ray scanning and profilometry of assemblies and fuel pins, fission-gas puncture analysis of fuel pins, and room-temperature tensile testing of steel samples cut from the assembly ducts. Density measurements and optical/electron microscopy of samples of assembly ducts and pin wirewraps were subsequently performed in the Alatau hot cells. Table lists the assemblies that were examined; they were chosen to bracket the condition of all assemblies in the spent fuel pool and included an assembly with failed fuel (C-19). The assessment also included a review of world experience with wet storage of spent fuel and a look at the results of previous destructive examinations of experimental BN-350 Type I and Type II core fuel pins. The objective of this assessment was to determine what measures should be taken to ensure the safety of packaging, transporting and dry storing the BN-350 spent fuel. The packaging phase of the collaborative project is described in a parallel paper by Lambert *et al.*

**Assemblies Used to Characterize BN-350 Spent Fuel**

| Assembly Type | Assembly Number | At.% Burnup | Discharge Date | Reason for Choice |
|---|---|---|---|---|
| Type I Core Nominal | C-105 | 5.0 | 04-20-78 | Oldest in wet storage |
| Type II Core Nominal | P-41 | 5.6 | 07-01-81 | Oldest in wet storage |
| Type II Core Experimental | C-19 | 12.8 | 17-10-91 | Failures; ferritic duct, high burnup/temp |
| Modernized Core Nominal | 715.17003188 | 7.4 | 12-04-92 | Oldest in wet storage |
| Modernized Core Experimental | C-8 | 8.5 | 20-11-93 | Austenitic duct; high burnup/temp |
| Outer radial blanket | N-081 | 0.23 | 01-07-77 | Oldest in wet storage |
| Outer radial blanket | N-214 | 0.50 | 15-05-93 | Highest burnup in pool |

Standard radial blanket assemblies were found to be in excellent condition after neutron damage doses of 10-12 dpa and water storage of up to 20 years. Corrosion of the 0.12C-18Cr-10Ni-Ti duct and cladding was superficial ($\leq 25$ μm) and neutron-induced swelling gave diameter increases of $\leq 1\%$ on both assembly ducts and fuel pin cladding. The austenitic ducts retained both high strength (~1000 MPa) and high plasticity (5-17%), in conformance with their low neutron damage doses ($\leq 12$ dpa). The axial distribution of $Cs^{134}$ and $Cs^{137}$ activities mirrored the expected variation in fission rates, indicating that Cs and other volatile fission products were immobile in the low temperature $UO_2$. Xenon and Kr were also immobile because essentially zero fission gas pressure was measured in the plenum space of the blanket pins.

Both Type II (1978-87) and Modernized (after 1987) designs of standard core assembly were generally in good condition after in-reactor exposure of 50-70 dpa and ~10 at.% burnup. The depth of corrosion after 5-15 years storage in the pool was measured as <50 μm for the austenitic steels 0.12C-18Cr-10Ni-Ti, 0.08C-16Cr-11Ni-3Mo and 0.08C-18Cr-15Ni-3Mo-1Nb, and the ferritic steel 0.12C-13Cr-2Mo-Nb-V-B. Fission product cesium was mobile in the core fuel pins, and gas release from the $UO_2$ fuel was 50-60%. Austenitic ducts and claddings had swollen significantly (~5% ΔD/D), whereas ferritic ducts exhibited ≤1% ΔD/D and near zero bowing. Austenitic ducts on standard Type I and Type II assemblies were found to retain 12-15% ductility and strengths of 700-800 MPa. Ferritic ducts on the standard Modernized core assemblies also retained high strength (600-1200 MPa) and low but adequate ductility (≥0.5%). In contrast, failed fuel pins in the high burnup assembly C-19 were found to have extremely brittle cladding, indicative of true exhaustion failure of the steel, a behavior believed typical of most BN-350 fuel failures. Similarly, the 0.12C-18Cr-10Ni-Ti (MTT) ducts on thirty experimental assemblies in the CC series exhibited strengths of <100 Mpa.

In summary, prolonged storage in water did not appear to have significantly degraded the condition of standard spent fuel assemblies from BN-350: corrosion was superficial and had caused no marked change in the mechanical properties of the irradiated steels. In many respects the results of the present characterization work endorsed experience elsewhere with stainless steel clad fuel in wet storage, which uniformly had shown a lack of significant corrosion. The BN-350 fuel differed in one important respect, however, from much of this past experience: it contained heavily sensitized cladding. That no problems were encountered during storage suggests that the high purity of the water in the storage pool, particularly its low chlorine content (0.1–0.3 mg/L), was likely to have contributed to this good behavior.

It was concluded that standard core and blanket assemblies retained sufficient mechanical stability to pose no risk during packaging and transportation. For further disposition these assemblies may simply be dried thoroughly and contained in inerted canisters. Drying and inerting is required to preclude the possibility of stress corrosion cracking of the sensitized claddings during prolonged storage at elevated temperature. In addition, assemblies containing failed fuel and/or brittle ducts should be doubly contained in order to ensure that a safe fuel geometry will be maintained during postulated packaging and transportation accidents.

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