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Transportation and Storage of MOX and LEU Assemblies at the Balakovo Nuclear Power Plant

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I. INTRODUCTION

The VVER-1000-type Balakovo Nuclear Power Plant has been chosen to dispose of the plutonium created as part of Russian weapons program. The plutonium will be converted to mixed-oxide (MOX), fabricated into assemblies and loaded into the reactor. Since the fresh and spent lead test assemblies (LTA) and mission fuel must be stored at the Balakovo reactor site, the configurations resulting from fresh and spent fuel storage and transportation within the plant were studied. This paper reports the results of criticality calculations for fresh MOX fuel assembly storage for one or two equilibrium reloads (20 to 40 assemblies), storage of spent MOX fuel assemblies (20 to 200 assemblies) and transportation of 16 fresh fuel assemblies within the plant.[1]

A configuration-controlled copy of version 4.3 of the Standardized Computer Analysis for Licensing Evaluation (SCALE),[2] known as SCALE4.3r, was used to perform criticality calculations. All calculations used the ENDF/B-V-based, 238-energy-group library. The CSAS6 sequence, which executes the modules BONAMI, NITAWL-II, and KENO-VI, was used to automate the cross-section processing and criticality calculations.

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VVER assemblies are hexagonal in shape and consist of a total of 331 pin-locations in a hexagonal array. Each assembly contains 312 fuel pins, 18 guide tubes, and 1 instrumentation tube. The pins are cylindrical and clad in zirconium. The assembly is loaded with several different types of fuel pins with differing fuel compositions. The LEU assembly contains 3.7-wt % and 4.2-wt % ^{235}U in U fuel pins, as well as uranium-gadolinium fuel pins. The MOX assembly contains 2.4-wt %, 2.7-wt % and 3.6-wt % ^{239}Pu in MOX fuel pins, as well as uranium-gadolinium fuel pins.

II. ANALYSES AND RESULTS

Fresh fuel is received at the plant by rail with units stacked on railroad cars. Two stainless steel canisters are welded together to a support structure to form a so-called *tyk* (*a Russian word translated as package-set*). Each canister contains one assembly (MOX or LEU). These tyks travel on railroad cars and are stacked 3-high and 2-wide. Upon arrival at the reactor site, the tyks are unloaded and stacked in the reactor building.

The k_{eff}'s for three dry cases were calculated. Cases 1 and 2 are six tyks containing all fresh LEU and MOX assemblies, respectively. Case 3 is for six tyks contaning fresh LEU assemblies, except the middle three are replaced by MOX assemblies to account for the case of a maximum of three lead test MOX assemblies being present at the site. A fourth case considers the storage of the tyks inside the reactor plant. Because the size of the fresh fuel storage area inside the plant is not known, a critical array search with fresh LEU assemblies was performed.

The data indicate that for these arrays of tyks with dry assemblies, k_{eff} values are well below the presumed upper subcritical limit. Case 4 data indicate that an infinite array (in three dimensions) of tyks with water at 0.2 g/cm^3 (optimum for maximum k_{inf}) density between the canisters results in $k_{inf} + 2\sigma$ of 0.7498, which is well below the presumed upper subcritical limit of 0.95. Therefore, a critical array of tyks in this configuration does not exist.

Before the fuel is loaded to the reactor, the tyks are up-ended and opened. Fresh fuel assemblies are then removed and placed in a transportation device called the fresh fuel transportation vehicle (FTV). The FTV has an inside diameter of 200 cm, and a wall thickness of 30 cm. The FTV can hold 18 assemblies. However, only 16 of these 18 positions are filled with assemblies.

The k_{eff}'s for nine cases were calculated. Cases 1 and 2 are 16 LEU and MOX assemblies, respectively. Case 3 is an array of LEU assemblies, except the middle three are replaced by MOX assemblies. Cases 1–3 do not contain any water. Cases 4–6 are the same configurations as 1–3, except the interstitial regions in the FTV and the fuel assemblies are occupied with full-density water. For Cases 7–9 the water density is assumed to be 0.2 g/cm^3. Cases 4–9 are reflected by water with the same density as the water in the FTV.

The data indicate that for the FTV with dry assemblies, the array of all MOX assemblies results in approximately 9% higher k_{eff} than the array of all LEU assemblies. For flooded FTV, however, the array of all LEU assemblies results in 3% higher k_{eff} than the array of all MOX assemblies. The highest k_{eff} + 2σ of 0.9356 was calculated when the water density was 0.2 g/cm^3 and the FTV contained an array of all LEU assemblies.

Because the controls on ensuring that the FTV is loaded with less than 16 assemblies are not known, the calculations were repeated with 18 assemblies to simulate a misload scenario. The data indicate the same trends as with maximum 16 assemblies in the FTV. However, the worst case with 18 LEU assemblies in the FTV with 0.2-g/cm^3-density water in the interstitial regions and in the FTV results in k_{eff} + 2σ of 0.9840, which is above the presumed upper subcritical limit of 0.95. The case with 15 LEU assemblies and 3 MOX assemblies results in k_{eff} + 2σ of 0.9686, which is also above the presumed upper subcritical limit.

The spent fuel storage pool holds 400 fuel assemblies. The fuel assemblies are stored in hexagonal canning tubes made of 1% borated-stainless steel, which makes it possible to increase the capacity of the storage pool by a factor of 2 over the original pool design capacity.

The k_{eff}'s for three cases were calculated. Cases 1 and 2 are fresh LEU and MOX assemblies, respectively. Case 3 is for an array of fresh LEU assemblies, except the three LEU assemblies in the center of the array are replaced by MOX assemblies. Although the problems concern the spent fuel in the spent fuel storage pool, all assemblies are assumed to be fresh (i.e., beginning-of-life compositions).

The data indicate that all configurations result in $k_{eff} + 2\sigma$ of less than 0.73, which is below the presumed upper subcritical limit.

III. CONCLUSIONS

Fresh fuel assemblies on the railroad platform, in fresh fuel storage, in the FTV, or in the spent fuel storage pool result in k_{eff}'s below the presumed upper subcritical limit and do not pose any concerns under normal operating conditions. However, for an accident condition of fully loaded FTV that is flooded with low-density water (possibly from a fire-suppression system), the presumed upper subcritical limit is exceeded by configurations containing LEU assemblies or LEU assemblies and 3 MOX LTAs. The misload scenario in the spent fuel storage pool, on the other hand, does not cause any significant change in the system k_{eff}, and therefore is not a concern.

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